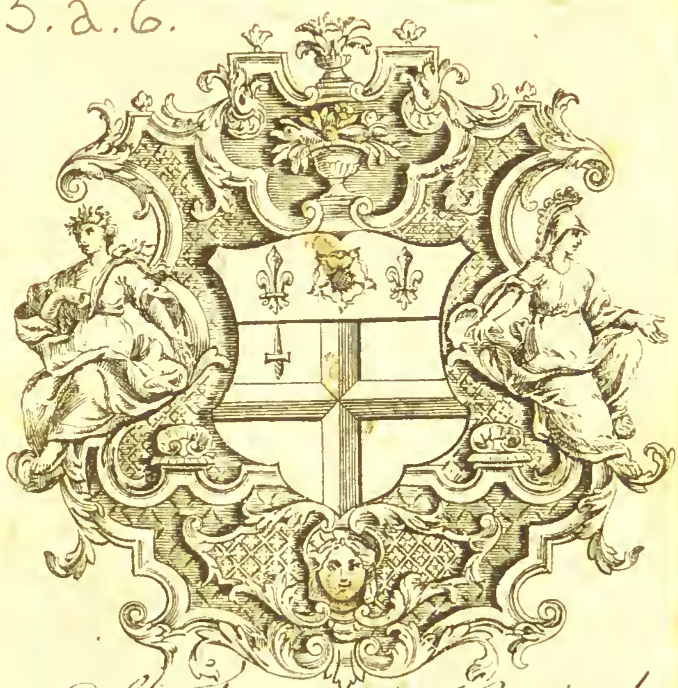


ELEMENTS

OF

PHYSICS,

OR

NATURAL PHILOSOPHY.

Written for General Use,

IN PLAIN OR NON-TECHNICAL LANGUAGE.

By NEIL ARNOTT, M.D., F.R.S., Etc.,

OF THE ROYAL COLLEGE OF PHYSICIANS; PHYSICIAN EXTRAORDINARY TO THE QUEEN; MEMBER OF THE SENATE OF THE UNIVERSITY OF LONDON;

ETC. ETC.

SIXTH AND COMPLETED EDITION.

PART I.

LONDON:

LONGMAN, GREEN, LONGMAN, ROBERTS, & GREEN.

1864.

751506
Tomus

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET
AND CHARING CROSS.

PREFACE

TO THE SIXTH AND COMPLETED EDITION.

Many readers will expect an explanation of the delay which has occurred in the completing of this work. Five large editions were called for within five years of its publication, although the concluding chapters on *Electricity* and *Astronomy* had not yet been printed. The book was translated into the principal languages of Europe, and various reprints were made in North America. The demand continued, but the Author was unwilling to go to press again until he could add the deficient chapters, —and impediments occurred. Besides increasing pressure of professional duties, there came a rapid succession of new marvels in advancing science and art, almost changing the state of the world, such as Railway travelling, Electrical telegraph, Steam navigation, and so forth, each of which required to be fully treated in a new edition. Then, the Author was requested by the General Board of Health to aid them, by written reports and otherwise, in public sanitary matters. And in 1836, when the Government founded the much desired University of London, the Author had the honour of being appointed a member of the Senate. Among the important labours of this Institution was the arrangement of the courses of study more

extended than heretofore, to be pursued by candidates for the University Degrees and honours as suited to the progressing state of society, which has since manifested itself by opening the road to high appointments, civil and military, at home and abroad, through competitive examinations in general knowledge. Owing to such causes the Author has had to delay the completion of his work until, by withdrawing from the active duties of his profession, he could command time to finish it to his satisfaction.

The first half of the complete work being now printed, the publishers advise its being issued without delay. It comprises the subjects contained in the first volume of the former editions, with the novelties which have since sprung up; thoroughly revised, and brought up to the present time, namely, MECHANICS, HYDROSTATICS, HYDRAULICS, PNEUMATICS, ACOUSTICS, and ANIMAL MECHANICS. The second half treats of the so-called *imponderables*—HEAT, LIGHT, ELECTRICITY and MAGNETISM, with ASTRONOMY, and it gives an outline of POPULAR MATHEMATICS.

Regent's Park, London,
January, 1864.

INTRODUCTION.

1. Importance of Physics.

To appreciate the importance of PHYSICS or NATURAL PHILOSOPHY, as a branch of study not only for all persons engaged in scientific pursuit, but, in the present day, for all who pretend to a moderately good education, we must take a rapid glance at the general nature of human knowledge, and at its bearings on the existing condition of mankind. We shall have to consider—

The progress of man, and stationary condition of inferior animals.
This progress more rapid at present than ever.
The divisions of human knowledge.
Natural Philosophy in detail.

---

2. Progress of Man, and stationary condition of inferior animals.

While the inferior races of animals on earth seem to have changed as little in any respect since the beginning of human records, as the trees and herbs of the thickets which give many of them shelter, the condition of man himself has been fluctuating, but, on the whole, has progressed in a very remarkable manner. The inferior animals were constituted by their Creator such, that within one life or generation they should attain all the perfection of which their nature was susceptible. Their important wants were either immediately provided for—as instanced in the clothing of feathers to birds, and of furs to quadrupeds; or were so simple, that the supply was easy to very limited powers—except in a few cases where considerable art was required, as by the bee in making its honey-cell, or by the bird in constructing its beautiful nest, and there, a peculiar aptitude or instinct was bestowed. Thus a crocodile which issues from its egg in the warm sand, and may not see its

parent, becomes as perfect and knowing as any crocodile that has lived before or that will appear after it.—But how different is the story when we turn to man! He comes into the world a being as helpless as can be conceived, long to continue such; and if deserted by parents at an early age, so that he can learn only what the experience of his own one life may teach him,—as to a few individuals has happened who yet have attained maturity in wild woods,—he grows up in some respects inferior to the nobler brutes. Now as regards many regions of the earth, history gives assurance that the early human inhabitants existed in states of ignorance and barbarism, not far removed from this lowest possible grade. But these countries, occupied formerly by straggling hordes of miserable savages, who could scarcely defend themselves against the wild beasts that shared the woods with them, and the inclemencies of the weather, and the consequences of want and fatigue, and who to each other were often more dangerous than any wild beasts, unceasingly warring among themselves, and destroying one another with every species of savage, and even cannibal cruelty—countries so occupied formerly, are now become, by gradual increase of knowledge, the abodes of myriads of peaceful, civilized, and friendly men, who have converted the desert and impenetrable forest into cultivated fields, rich gardens, and magnificent cities.

3. Language the great instrument of progress.

It is the strong intellect of man, operating with the faculty of language as a means, which has gradually worked this wonderful change. By language fathers communicated their gathered experience and reflections to their children, and these to succeeding children, with new accumulation; and when, after many generations, the precious store had grown until simple memory could retain no more, the arts of writing, and then of printing, arose, making language visible and permanent, and enlarging illimitably the repositories of knowledge. Language thus, at the present moment of the world's existence, may be said to bind the whole human race of uncounted millions into one gigantic rational being, whose memory reaches to the beginnings of written records, and retains imperishably the important events that have occurred; whose judgment analyzing the treasures of memory, has discovered many of the sublime unchanging laws of nature, and has built on them all the arts of life, and through them, piercing far into futurity, sees clearly many of the events

that are to come; and whose eyes and ears and observant mind at this moment, in every corner of the earth, are watching and recording new phenomena, for the purpose of still better comprehending the magnificence and perfect order of creation, and of more worthily conceiving of its beneficent Author.

4. The progress more rapid in late times than ever.

"It might be very interesting to show here, in particular instances, how the arts and civilization have progressed in accordance with the gradual increase of man's knowledge of the universe; but to do this would lead too far from the main object. We deem it right, however, at once to make the student aware of the arousing truths, that the progress is not yet at an end; that it has been vastly more rapid in recent times than ever, and is still proceeding with increasing celerity:—and we know not where the Creator has fixed the limits of the change! Although there are thousands of years on the records of the world, our BACON, who first explained clearly the way to investigate nature, lived but the other day. NEWTON followed him, and illustrated good methods by the most sublime discoveries which one man has ever made. HARVEY detected the circulation of the blood only about two hundred years ago. ADAM SMITH, DR. BLACK, and JAMES WATT were friends, and the last, whose steam-engines are now changing rapidly the condition of the world, may be said to be scarcely cold in his grave. JOHN HUNTER died not long ago; HERSCHEL'S reports of newly-discovered planets, and of the now ascertained sublime structure of the heavens, and DAVY'S account of chemical discoveries scarcely less important to man, are in the late numbers of our scientific journals. On the continent of Europe, during the same period, a corresponding constellation of genius has appeared; and LAPLACE was lately the bright star shining between the future and the past."

5. Inventions and Discoveries of last half-century.

The above paragraph was written for the first edition of this work, and it is retained in the present unchanged, as affording striking evidence of the truth asserted in it, that human knowledge and art have been progressive in the world, and are now advancing with accelerated speed. The discoveries and inventions there referred to were the most remarkable which had occurred within tho two preceding centuries; but if such a

sketch had to be written for the present day, it would have to include much more. Within the last half century there have sprung up and spread, 1st. The art of lighting by gas, which, from a narrow beginning, has grown to universal adoption, almost converting night into day wherever civilized men are gathered together; 2nd, The locomotive engines for railways have been invented, which are now almost annihilating distance on land, and changing the face of every civilized country; 3rd, Then steam navigation on the high seas has been established, and now sets at defiance the force of winds and waves, of which mariners were formerly the slaves; 4th, The electrical telegraph has been realized, and is extending over the world, so that a message may be sent, and the answer received, over thousands of miles, within a few minutes; 5th, The penny postage has come into use, and for a penny a letter is conveyed from one extremity of the kingdom to another at the rate of forty miles an hour. Within the same short time, other novelties of great importance have appeared, as photography, the stereoscope, &c.; but, clearly, if any one of the five above noted particulars were again to be lost to the world, a vast gap would be left in modern civilization.

6. The diffusion of existing Knowledge as important as new discovery.

But there is a change going on in the world, connected closely with the progress of science, yet distinct from it, and not less important than many of the scientific discoveries themselves;—it is the *diffusion of existing knowledge* among the mass of mankind. Formerly knowledge was shut up in convents and universities, and in books written in the dead languages—or in books which, if in the living languages, were so abstruse and artificial, that only a few persons had access to their meaning; and thus, the human race being considered as one great intellectual creature, a small fraction only of its intellect was allowed to come into contact with science, and therefore into activity. The progress of science in those times was correspondingly slow, and the evils of general ignorance prevailed. Now, however, the strong barriers which confined the stores of wisdom have been thrown down, and a flood is overspreading the earth; old establishments are adapting themselves to the spirit of the age; new establishments are arising; the inferior schools are introducing improved systems of instruction; and good books are rendering every man's fireside a school. From all these causes

there is growing up an *enlightened public opinion*, which quickens and directs the progress of every art and science, and through the medium of a free press, although overlooked by many, is now rapidly becoming the governing influence in all the affairs of man.

7. Influence of Public Opinion shown in the history of Britain and its Colonies.

In Great Britain, partly perhaps as a consequence of its insular situation, which lessened among its inhabitants the dread of hostile invasion, and sooner formed them into a united and compact people, the progress of enlightened opinion had been more decided than in other states. The early consequences were, more free political institutions ; and these gradually led to greater and greater improvements, until Britain became an object of admiration among the nations. Colonies of her children trained more or less in her ways, now occupy extensive territories in various parts of the earth, and are increasing in population, wealth, and power, as colonies never did before. Some of these in mere extent and population will soon surpass greatly the parent state. It could not be expected, however, that they all would escape such severe trials as most other communities have passed through in their early stages ; and accordingly, as was foreseen and foretold by profound thinkers like Macaulay, De Tocqueville, and others with respect to the United States of North America, certain defects in their constitution have aroused among them at this time most deplorable strife. This condition, however, will naturally soon come to an end, and we may hope that it will serve in the future as an effectual warning against like evils to the present sufferers and to others.

In the still more recently discovered continent of Australia, which is nearly as large as Europe, and is empty of men, colonization is spreading with a rapidity never before witnessed ; and that beautiful and rich portion of the earth will also soon be covered with the descendants of free-born Englishmen. From thence, still onward, they or their institutions will naturally spread over the vast archipelago of the Pacific Ocean, a track studded with islands of paradise. Such, then, is the extraordinary moment of revolution or transition in which the world at present exists ! And where, it may be again asked, has the Divine Author of all willed that the progress shall cease ? Thus far at least we know, that He has made our hearts rejoice to see

the world likely to be filled with happy human beings, and to observe that the increase of the sciences can make the same land maintain thousands in comfort and noble elevation of mind, where during ignorance even hundreds had found but a scanty and almost brutish sustenance.

8. Progress of Knowledge has advanced in clearly marked directions.

The progress of knowledge which has thus led from former barbarism to present civilization, has gone on in certain clear directions, which it is easy to point out; and which it is very useful to consider, because we thereby understand better the nature of human knowledge, with the relations and importance of its different branches; and we obtain new facilities for studying science, and for quickening further progress.

9. The Mind discovers resemblances among things, and classifies them as three Kingdoms of Natural History.

The human mind, when originally directed to the almost infinity of objects in the universe around it, must soon have discovered that there were resemblances among them; in other words, that the infinity was only a repetition of a certain number of kinds. Among animals, for instance, it would distinguish the kinds called the sheep, the dog, the horse; among vegetables, the oak, the beech, the pine; among minerals, lime, flint, the metals, and so forth. And becoming aware that by studying an exemplar of each kind, its limited power of memory might acquire a tolerably correct knowledge of the whole, while this knowledge would enable the possessors more easily to obtain what was useful to them, and to avoid what was hurtful, the desire for such knowledge must have arisen with the first exercise of reason. Accordingly, the pursuit of it has been unremitting, and the labour of ages has at last nearly completed an arrangement of the constituent materials of the universe, under three great classes of MINERALS, VEGETABLES, and ANIMALS; commonly called the *three kingdoms of Nature*, and of which the minute description is termed NATURAL HISTORY: and museums of natural history have been formed which contain specimens of almost every object included in these classes, so that now, a student, within the limits of an ordinary garden, may be said to be able to survey generally the material universe.

10. The Mind discovers resemblances also among phenomena, and classifies them under four Departments of Science.

While men were examining the *forms* and other fixed qualities of the bodies around them, they could not avoid noticing also the *motions* or changes going on among bodies; and here, too, they would soon make the grand discovery, that there were resemblances in the multitude. Self-interest, as in the case of the bodies themselves, having prompted to careful classification, we are enabled in the present day, as the result of countless observations and experiments made through the series of ages, to say, that all the *motions*, or *changes*, or *phenomena* (words synonymous here) of the universe, are merely a repetition and mixture of a few simple manners or kinds of motion or change, which are as constant and regular in every case, as where they produce the returns of day and night, and of the seasons. All these phenomena are referable to four distinct classes, which we call *Physical*, *Chemical*, *Vital*, and *Mental*. The simple expressions which describe them are denominated *General Truths* or *Laws of Nature*, and as a body of knowledge, they constitute what is called SCIENCE or PHILOSOPHY, in contradistinction to NATURAL HISTORY, already described. Now as man cannot, independently of a supernatural revelation, learn anything but what respects, 1st, the momentary state, past or present, of himself and the objects around him; and 2nd, the manner in which the states have changed: *Natural History* and *Science*, in the senses now explained, make up the whole sum of his knowledge of nature.

11. This process exemplified in regard to Gravitation.

To exemplify the process by which a general truth or law of nature is discovered, we shall take the physical law of *gravitation* or *attraction*. 1st. It was observed that bodies in general, if raised from the earth, and left unsupported, fell towards it; while flame, smoke, vapours, &c., if left free, ascended away from the earth. It was held, therefore, to be a very general law, that things had *weight*; but that there were exceptions in such matters as now mentioned, which were in their nature *light* or ascending. 2nd. It was discovered that our globe of earth is surrounded by an ocean of air, having nearly fifty miles of altitude or depth, and of which a cubic yard, taken near the surface of the earth, weighs about ten ounces. It was then perceived

that flame, smoke, vapour, &c. rise in the air only as oil rises in water, *viz.* because not so heavy as the fluid by which they are surrounded: it followed, therefore, that nothing was known on earth naturally *light*, in the ancient sense of the word. 3rd. It was found that any contiguous hanging bodies were drawn towards each other, so as not to hang quite perpendicularly; and that a plummet suspended near a hill was drawn towards the hill, with force only so much less than that with which it was drawn towards the earth, as was due to the differences of size and distance, according to the ascertained law. It was thus proved that weight itself is only an instance of a more general *mutual attraction*, operating between all the constituent elements of this globe. This explained, moreover, the fact of the rotundity of the globe, all the parts being drawn towards a common centre, as also the form of dew-drops, rain-drops, globules of mercury, and of many other such things. 4th. It was farther observed, that all the heavenly bodies are round, and must, therefore, consist of material obeying the same law. 5th. And lastly, that these bodies, however distant, attract each other; for that the tides of our ocean rise in obedience to the attraction of the moon when she appears over them, and become *high* or *spring-tides*, when the moon and sun are operating in the same direction. Thus the sublime truth was at last made evident, and by the genius of the immortal Newton, that there is a power of attraction connecting together the bodies of this solar system at least, and probably limited only by the bounds of the universe.

12. Slow discovery of the laws of Science has allowed certain superstitions long to prevail.

Acquaintance with the laws of nature has been very slowly obtained, owing to the complexity of ordinary phenomena, which is produced by several laws operating together, and under great variety of circumstances. With respect to many laws of Chemistry and Life, men seem to be as yet little further advanced than they were with respect to the physical law of *attraction*, when they knew only that heavy things fell to the earth. But we have learned enough to perceive that the great universe is as simple and harmonious as it is immense; and that the Creator, instead of interposing separately, or miraculously, in the common sense of the word, to produce every distinct phenomenon, has willed that all should proceed according to a few general laws. There is nothing in nature so truly miraculous as that

the endless and beneficent variety of results which we see should spring from such simple elements. In times of ignorance men naturally regarded every occurrence which they did not understand, that is to say, which they could not refer to a general law, as resulting from a direct interference of supreme power; and thus for many ages, and among some nations still, eclipses, and earthquakes, and many diseases, particularly those of the mind, and the winds and weather, were or are accounted miraculous. Hence arose among heathens many ceremonies, and sometimes even barbarous human sacrifices, for propitiating or appeasing their supposed deities; but founded on expectations no more reasonable than if we should now pray to have the day or the year made shorter, or to have a coming eclipse averted. They had not yet risen to the sublime conception of the One God, who could say, "Let there be light," and the light was; and who could give to the whole of nature permanent laws, which men would discover for the direction of their conduct in life—laws so unchanging, that by them men can now calculate eclipses backward or forward for thousands of years, almost without erring, by a few beats of a pendulum; and as their knowledge of nature advances, can anticipate and explain other events with equal precision. Even the wind and the rain, which in common speech are the types of uncertainty and change, obey laws as fixed as those of the sun and moon; and already, as regards many parts of the earth, man can foretel them without fear of being deceived. He plans his voyages to suit the coming monsoons, and he prepares against the floods of the rainy seasons.

13. The advantages of knowing the General Laws.

He who understands the laws of nature even in the degrees in which men now know them, has such foresight of the future, and of the effects which will arise from certain causes, that in many instances he can interpose and control events to answer his private ends. To a certain extent he thus commands nature, seeming to prove that knowledge is power. Moreover, as all single material objects and states of objects in the universe are results of antecedent operation of the laws of change, a man who early learns the laws knows beforehand great part of the objects and changes which he will meet with, and thus most remarkably diminishes the labour of studying natural history. He seems to learn by intuition. But he has still to be on his

guard not to push his conjectures too far. All his calculations are yet founded on the assumption that the course of nature as understood by him has not changed, and will not change. Now, although thousands of years give countenance to the assumption, these thousands are less to a past and coming eternity than a noonday hour which is an animalcule's life, to rolling ages—an animalcule which cannot know the morning nor the evening, nor spring nor winter. Man can foretell the change of day and of season and the coming of remote eclipses; but stars which his forefathers beheld bright in the firmament are now dim or have disappeared—an example of awful changes of which his knowledge founded on short human experience can tell him neither the beginning nor the end.

14. The four Classes of General Laws.

The general laws of nature, divisible as stated above, into the four classes of, 1st, *Physics*, often called *Natural Philosophy;* 2nd, of *Chemistry;* 3rd, of *Life,* commonly called *Physiology;* and 4th, of *Mind,* may be said to form the pyramid of Science, of which Physics is the base, while the others constitute succeeding layers in the order now mentioned; the whole having certain mutual relations and dependencies well figured by the parts of a pyramid. We must describe them more particularly, to show these relations.

15. Physics; or, Natural Philosophy.

The laws of *Physics* govern every phenomenon of nature in which there is any sensible change of place, being concerned alone in the greater part of these phenomena, and *regulating* the remainder which originate from chemical action, and from the actions of life.—The great Physical truths, as comprehended in the present day by man, are reduced to four, and are referred to by the words *atom, attraction, repulsion,* and *inertia.* It gives an astonishing, but true idea of the nature and importance of methodical *Science,* to be told that a man, who understands these words, *viz.,* how the ATOMS of matter by mutual ATTRACTION approach and cling together to form masses, which are solid, liquid, or aëriform, according to the quantity or REPULSION of heat among them, and which, owing to their INERTIA or stubbornness, gain and lose motion, in exact proportion to the force acting on them,—understands the greater part of the phenomena of nature; but such is the fact! *Solid* bodies existing

in conformity with these truths, exhibit all the phenomena of *Mechanics*; *Liquids* exhibit those of *Hydrostatics* and *Hydraulics*; *Airs*, those of *Pneumatics*; and so forth, as seen in the table of heads given below, at page xix. And the whole of this work is merely a series of the most interesting physical phenomena, arranged in classes under these heads.

16. Chemistry.

Had there been only one kind of substance or matter in the universe, the laws of Physics would have explained all the phenomena; but there are *iron*, and *sulphur*, and *charcoal*, and about fifty others, which, to the present state of science, appear essentially distinct. Now these, when taken singly, obey the laws of Physics; but when two or more of them are placed in contact under certain circumstances, they exhibit new orders of phenomena. Iron and sulphur, for instance, brought together and heated, disappear as individuals, and unite into a yellow apparently metallic mass, which in most of its properties is unlike to either:—under other new circumstances, the two substances will again separate, and assume their original forms. Such changes are called *chemical* (from an Arabic word signifying *to burn*, because so many of them are effected by means of heat,) but during the changes, the substances are not withdrawn from the influence of the physical laws,—their weight or inertia, for instance, is not altered; and indeed the phenomenon is merely a modification of general *attraction* and *repulsion*. Many chemical changes besides are only the beginnings of purely mechanical changes, as when the new chemical arrangement produced by heat among the ultimate atoms of gunpowder causes the mechanical or physical motion of the sudden expansion or explosion. And all the manipulations of Chemistry, as the transferring of gases from vessel to vessel, the weighing of bodies, pounding, grinding, &c., are directed by Physics alone. Chemistry, then, is truly, as figured above, a superstructure on Physics, and cannot be understood or practised by a person who is ignorant of Physics.—The chief departments of study involving the consideration of Chemical in conjunction with Physical laws, are enumerated in the table below, under the head of CHEMISTRY.

17. Life.

The most complicated state in which matter exists, is where, under the influence of life, it forms bodies with a curious internal structure of tubes and cavities, in which fluids are moving and producing incessant internal change. These are called *Organized Bodies,* because of the various distinct parts or *organs* which they contain; and they form two remarkable classes, the individuals of one of which are fixed to the soil, and are called *Vegetables;* and of the other, are endowed with power of locomotion, and are called *Animals.* The phenomena of growth, decay, death, sensation, self-motion, and many others, belong to life, but from occurring in material structures which subsist in obedience to the laws of physics and chemistry, the life is truly a superstructure on the other two, and cannot be studied independently of them. Indeed the greater part of the phenomena of organic life are merely chemical and physical phenomena modified by an additional principle.—The Science of *Life* is divided into *animal* and *vegetable Physiology* (*see the table below*).

18. Mind.

The most important part of all science, is the knowledge which man has obtained of the laws influencing the operations of his own MIND. This department stands eminently distinct from the others, on several accounts. Unlike that of *organic life,* which could not be understood until physics and chemistry had been previously investigated, this had made extraordinary advances in a very early age, and when the others, as methodical sciences, had scarcely begun to exist. In proof of this assertion we need only refer to the writings of the Greek philosophers. Brilliant discoveries and applications, however, were reserved for the moderns, as will occur to readers, on perusing in the table below, the several divisions of the subject, and on recollecting the honoured names which are now associated with each. The study of the laws of mind, according to the true mode of research, namely, by *induction,* was delayed because the impression existed, that to admit the possibility of fixed laws of mental action, was almost to allow that there is not human free-will and responsibility; but closer examination shows this to be a misconception. No one denies, for instance, that there is a law of memory which compels a learner to read or to hear several times any verbal composition which is afterwards to be repeated without book, and there are similar laws with respect to the other faculties.

The crowning science of Mind, although in certain respects independent of the sciences of Matter, is still closely allied to them in the following ways. The faculties of the mind are originally awakened or called into activity solely by the impressions of matter on the bodily senses; all the language used in speaking of mind and its operations, is borrowed from matter; and many mental emotions are entirely dependent on bodily conditions. The science of Mind, therefore, cannot be studied until after knowledge acquired of an external nature; and cannot be studied extensively until that knowledge is extensive.

19. Language.

To any new object found, or new phenomenon seen, or new invention made, men naturally give a name, so that it may be referred to in future conversation. Such process must have been going on from the earliest times. Names so given differ much in different countries, as depending altogether on the will of the individuals suggesting the names and the surrounding circumstances. Thus have present languages been built up by human art.

20. Measures.

To express most of the facts and laws of physics, chemistry, and life, terms of QUANTITY or measure are required, as when we speak of the magnitude or shape of a body, or say, that the force of attraction between two bodies diminishes, in a certain proportion, as their distance increases. Hence arises the necessity of having a set of fixed measures or standards, with which to compare all other quantities. Such measures have been taken chiefly from the human body; and they are, for NUMBERS, the fingers, or *fives* and *tens*; for LENGTH, the *human foot, cubit, pace*, &c. (and lately, since men have been able to measure the circumference of the earth, they take the metre, which is a fraction of that); for SURFACES, the simplest forms of *circle, square, triangle*, &c., compared among themselves by the lengths of their diameters or other suitable lines; and for SOLID BULK, the corresponding simple solids, of *globe, cube, pyramid, cone*, &c., similarly compared by the lengths of diameters or of other lines of dimension. The rules for applying these standards to all possible cases, and for comparing all kinds of quantities with each other, constitute a body of knowledge, called the *Science of Quan-*

tity, or the *Mathematics*. It may be considered as an additional department of human knowledge and art, created by the mind itself, to facilitate the study of the others.

21. Arts are built on Science.

The mental powers which enable a man to acquire a knowledge of objects, and to discover a certain order or course in the changes among these, and to anticipate the same in the future —in other words, which enable him to learn natural history and science—would still have left him but as a dreamer on earth, or a mere looker-on, had he not possessed a body susceptible of pleasure and pain, and those bodily powers which allow him to a certain degree to mix himself up with passing events so as to turn them to his advantage. When he does so use his powers, he is said to exercise an art. It is important here to remark, that while originally acquiring his knowledge of the course of nature, he is connecting in his mind ideas in the order in which nature herself presents them to him, but for the purposes of *art* he has to acquire the facility of reading such lessons backward too, for in every case he has to keep present to his mind, as one link of various chains of sequence, the object or end sought by his art, and then to look backward from it along all the chains of events known to him which lead to it, that he may choose among them that one in which his bodily powers may with the least trouble to him become an introducing or determining link.

22. Professions among Men have regard to the different Arts.

Supposing *description of particulars*, or *Natural History*, to be studied along with the different parts of the *System of Science* sketched in the table, there will be included in the scheme the whole knowledge of the universe which man can acquire by the exercise of his own powers. And on this knowledge all his arts are founded,—some of them on the single part of Physics, as that of the machinist, architect, mariner, carpenter, &c.; some on Chemistry (which includes Physics), as that of the miner, glass-maker, dyer, brewer, &c.; and some on Physiology (which includes much of Physics and Chemistry), as that of the scientific gardener or botanist, agriculturist, zoologist, &c. The business of teachers of all kinds, and of governors, advocates, linguists, &c. &c., respects chiefly the science of Mind. The art of medicine requires in its professor a comprehensive knowledge of all the departments.

23. Table of Science and Art.

1. PHYSICS.	2. CHEMISTRY.
Mechanics, Hydrostatics, Hydraulics, Pneumatics, Acoustics, Heat, Light, Electricity, Astronomy, &c.	Simple substances, Mineralogy, Geology, Pharmacy, Brewing, Dyeing, Tanning, &c.
3. LIFE.	**4. MIND.**
Vegetable Physiology, Botany, Horticulture, Agriculture, &c. Animal Physiology, Zoology, Anatomy, Pathology, Medicine, &c.	*Intellect*, Logic, Mathematics, &c. *Motives to Action*, Emotions and Passions, Morals, Government, Political Economy, Education, THEOLOGY.

24. Education may be according to accident or to method.

In the first stages of education, *viz.* during the years of childhood and early youth, the learning acquired is necessarily of the most mixed kind, being chiefly determined by what is called accident; but from the mutual dependence of the different departments of science, as explained in the preceding paragraphs, it follows that, with a view to complete erudition, the order exhibited in "The Table" is that in which they should afterwards be studied and arranged in the mind in detail, so as to prevent useless repetitions and anticipations.

25. Picture of unmethodical Education.

Every man may be said to begin his education, or acquisition of knowledge, on the day of his birth. Certain objects, repeatedly presented to the infant, are after a time recognized and distinguished. The number of objects thus known gradually increases, and from the constitution of the mind, they are soon associated in the recollection, according to their resemblances, or obvious relations. Thus sweetmeats, toys, articles of dress, &c. soon form distinct classes in the memory and conceptions of

children. At a later age, but still very early, the child distinguishes readily between a *mineral* mass, a *vegetable*, and an *animal;* and thus his mind has already noted the three great classes of natural bodies, and has acquired a certain degree of acquaintance with *Natural History.* He also soon understands the phrases "a falling body," "the force of a moving body," and has therefore a perception of the great physical laws of gravity and inertia. Then having seen sugar dissolved in water, or marble in an acid, and wax melted round the wick of a burning candle, he has learned some phenomena of Chemistry. And having observed the conduct of the domestic animals, and of the persons about him, he has begun his acquaintance with Physiology and the Science of Mind. Lastly, when he has learned to count his fingers and his sugarplums, and to judge of the fairness of the division of a cake between himself and his brothers, he has advanced into Arithmetic and Geometry. Thus, within a year or two, a child of common capacity has made a degree of progress in all the great departments of human knowledge; and in addition has learned to name objects, and to express feelings, by the arbitrary sounds of language. Such, then, are the beginnings or foundations of knowledge, on which future years of experience, or methodical education, must rear the superstructure of the more considerable attainments which befit the various conditions of men in a civilized community.

26. Natural Philosophy has not in common Education been treated as fundamental, owing to two misconceptions.

In the course of the preceding disquisition, we have seen that *Physics* or *Natural Philosophy,* the subject of the present volume, is fundamental to the other parts, and is therefore that of which a considerable knowledge is indispensable in a sound education. Bacon truly calls it "the root of the sciences and arts." That its importance has not been marked by the place which it has held in common plans of education, is owing chiefly to two causes, 1st, the misconception that deep knowledge of technical mathematics, which only a few have leisure to acquire, was a necessary preliminary; and 2nd, to an opinion that the degree of acquaintance with Physics which persons almost unavoidably acquire by common experience in the world, is sufficient for common purposes.

27. Abstract Mathematics and the popular Mathematics of common experience.

Now it is true that a certain amount of mathematical knowledge is necessary to the student, but it is equally true that the mathematical knowledge acquired by individuals generally in the common experience of early years, along with the commencements of Physics, Chemistry, and Physiology, as already explained, is sufficient to enable students, with a little help, to comprehend the fundamental laws of nature; nearly as the knowledge of language obtained at the same time and in the same way is sufficient, without previous study of abstract grammar, to enable persons to understand conversation on all common subjects. Few persons in civilized society are so ignorant as not to know that a square has four equal sides and four equal corners or angles, that every point in the circumference of a circle is at the same distance from the centre, or who does not immediately discover whether a tree or pillar seen, stands upright or leans, whether a table be level or inclined, whether two lines are parallel or not, and so forth. Now these are nice mathematical perceptions, and it will be shown in the Mathematical Appendix to this work that such truths reach far in explaining the great phenomena of nature.

28. Natural Philosophy, learnt from toys, &c., very imperfect.

It is true that the toys of childhood, as the windmill, ball, syphon, tube, and a hundred others, furnish so many exemplifications of the laws of Physics, and may well be classed with the familiar tools of carpenters, masons, &c., as philosophical apparatus; but they give information which is exceedingly vague, and not at all such as is requisite in the practice of the arts.

29. The above misconceptions have arisen from narrow views of general knowledge.

The above misconceptions, and others, arise from persons not having been early led to form some conception of the general field of human knowledge, with its subdivisions. He whose view is bounded by the limits of one or two small departments, will probably have very defective notions even of these, but certainly will, of other parts, and of the whole, so as to be constantly exposed to err hurtfully to himself and to others. His narrow mind, compared with that of a better-educated man, is

what the mis-shapen body of a mechanic crippled by an unhealthy trade is to the body of an active mountaineer.

30. The greatest sum of knowledge gained with the least trouble comes with the study of the Laws of Physics.

The greatest sum of knowledge acquired with the least trouble, is perhaps that which comes with the study of the few simple truths of Physics. To the man who understands these, very many phenomena, which to the uninformed appear prodigies, are only beautiful illustrations of his fundamental knowledge, and this he carries about with him, not as an oppressive weight, but as a kind of charm supporting the weight of other knowledge, and enabling him to add to his valuable store every new fact of importance which may offer itself. With such a principle of arrangement, his information, instead of resembling loose stones or rubbish lying together in confusion, becomes as a noble edifice, of correct proportions and firm contexture, and is acquiring greater volume and consistency with the experience of every day. It has been a common prejudice, that persons thus instructed in general laws, had their attention too much divided, and could know nothing perfectly. But the very reverse is true; for general knowledge renders all particular knowledge more clear and precise. The ignorant man may be said to have charged his hundred hooks of knowledge, to use a rude simile, with single objects, while the informed man makes each support a long chain, to which thousands of kindred and useful things are attached. The truths of Philosophy may be compared to keys which give admission to the richest gardens that fancy can picture; or to a magic power, which unveils the face of the universe, and discloses endless charms of which ignorance never dreams. The informed man, in the world, may be said to be always surrounded by what is known and friendly to him, while the ignorant man is as one in a land of strangers and enemies. A man reading a thousand volumes of ordinary books as agreeable pastime, will retain only vague impressions; but he who studies the methodized *Book of Nature*, converts the great universe into a simple and sublime history, which is constantly telling of its Maker, and may worthily occupy a man's attention to the end of his days.

31. All works of Engineering are founded on those laws.

We have said already, that the laws of Physics govern the great *natural* phenomena of Astronomy, the tides, winds, currents, &c. We are now to mention some of the *artificial* purposes to which man's ingenuity has made the same laws subservient.

Nearly all that the civil engineer accomplishes ranges under the head of Physics. Let us take, for instance, the admirable specimens scattered over the British Isles :—the numerous rail-roads and canals for inland traffic; the docks to receive the riches of the world, pouring towards us from every quarter; the many harbours offering safe retreat in all weathers to the mariner; the magnificent bridges which everywhere facilitate intercourse; hills bored through to open passage for the roads and canals; vast tracts of swamp or fen-land drained, and now serving for agriculture; the noble lighthouse, standing firm amidst the storm, while the dweller within trims his lamp in safety, and guides his endangered fellow-men through the perils of the night, &c. &c.

In Holland, great part of the country has been won and is now preserved from the sea, by the same almost creating power; and there rich cities and an extended garden now smile, where, in the days of Julius Cæsar, there were only bogs and a dreary waste.

32. Contrast between ignorant savages, and people who have engineering arts.

As a general picture it is interesting to consider, that in many situations on earth where formerly the rude savage beheld the cataract falling among the rocks, and the wind bending the trees of the forest, and sweeping the clouds along the mountain's brow, or whitening the face of the ocean, and regarded these phenomena with awe or terror, as marking the agency of great but hidden powers which might destroy him; in the same situations now, his informed son, who works with the laws of nature, can lead the waters of the cataract, by sloping channels, to convenient spots, where they are made to turn his mill-wheel, and to do his multifarious work; the rushing winds, also, he makes his servants, by rearing in their course the broad-vaned windmill, which then performs a thousand offices for its master, man; and the breezes everywhere which stir the ocean are

caught in his expanded sails, and are made to waft their lord and his treasures across the deep, for his pleasure or his profit.

In Architecture, also, Physics is supreme, and has directed the construction of the temples, pyramids, domes, and palaces which adorn the earth.

In respect to machinery generally, Physics is the guiding light. There are, for instance, the mighty steam-engine; machines for spinning and weaving, and for moulding other bodies into various shapes, yea, even iron itself, as if it were plastic clay; windmills, and watermills, and wheel carriages; the plough, and implements of husbandry; artillery and the furniture of war; the balloon, in which man looks around from above the clouds, and the diving-bell, in which he can penetrate the secrets of the deep; the implements of the intellectual arts, of printing, drawing, painting, sculpture, &c.; musical instruments; optical and mathematical instruments, and a thousand others.

33. Physics all-important to Medical Practitioners.

And Physics is also an important foundation of the healing art. The medical man, indeed, is the engineer pre-eminently; for it is in the animal body that the highest perfection and the greatest variety of mechanism are found. Where, to illustrate *Mechanics*, is to be seen a system of levers and hinges, and moving parts, like the limbs of an animal body; where such an *hydraulic* apparatus, as in the heart and blood-vessels; such a *pneumatic* apparatus, as in the breathing chest; such *acoustic* instruments, as in the ear and larynx; such an *optical* instrument, as in the eye; in a word, such variety and perfection, as in the whole of the visible anatomy? All these structures, then, the medical man should understand, as a watchmaker knows the parts of a time-piece which he is intrusted to repair. The watchmaker, unless he can discover where a pin is loose, or a wheel injured, or a particle of dust adhering, or oil wanting, &c., would ill succeed in restoring efficiency; and so also of the ignorant medical man in respect of the human body. Yet it is true that not long ago there were medical men allowed to practise, who neither understood mechanics, nor hydraulics, nor pneumatics, nor optics, nor acoustics, beyond the merest routine; and that plans of medical education were tolerated which hardly noticed the department of *Physics!* That such was the case, furnishes an illustration of what is stated in the beginning of

this essay; *viz.* that the sciences and arts have all been progressive, and that improved methods of education had to arise gradually, like all other things of human contrivance. It is within the recollection of persons now living, that political economy was discovered to be a grand foundation of the art of government, teaching the means of security against many national calamities common in former times, not excepting even famine and war. And the day is probably arrived, when the members of the medical profession generally will understand how very much the correct knowledge of animal structure and function, and of remedial means, depends on precise acquaintance with Physics.—Besides the strictly professional matters bearing on the treatment of disease, there are in physics many others of a more general character bearing on prevention; such are the subjects of *meteorology, climate, ventilation,* and *warming* of dwellings, &c. &c.

34. Persons of all classes have need to study Natural Philosophy.

The laws of Physics having an influence so extensive as appears from these paragraphs, it need not excite surprise that all classes of society are at last discovering the deep interest they have to understand them. The *lawyer* finds that in many of the causes tried in his courts, an appeal must be made to Physics,—as in cases of disputed inventions; accidents in navigation, and travelling, disputes respecting steam engines, and machines generally; questions arising out of the agency of winds, rains, water-currents, &c.: the *statesman* in Parliament is constantly listening to discussions respecting bridges, roads, canals, docks, telegraphs, and the mechanical industry of the nation: the *clergyman* finds everywhere among the facts of nature, the most intelligible and striking proofs of God's wisdom and goodness; the *sailor* in his ship has to deal with one of the most admirable machines in existence: and *soldiers*, while studying how to defend their country, find its safety and its rank among the nations to depend greatly on the perfection to which their knowledge of Physics has brought their rifled artillery, their iron-clad ships, and other parts of their military engineering: the *land-owner*, in making improvements on his estates, building, draining, irrigating, road-making, &c.: the *farmer* equally in these particulars, and in all the machinery of agriculture: the *manufacturer*, of course, to the widest extent: the *merchant* who has to purchase, and distributes over the world the products of manu-

facturing industry—all these are interested in Physics; and even the *man of letters*, that he may not, in drawing illustrations from the material world, repeat the scientific heresies and absurdities which have heretofore prevailed, and which, by shocking the now better-informed public, would lower the estimation in which literature should be held; and, lastly, *parents of either sex*, whose conversation and example have such powerful effect on the character of their children, who are rising to be their successors;—all should have knowledge of Physics, as one important part of their educational acquirements.

35. And now all classes do more or less engage in the study.

It is for such reasons that Natural Philosophy is becoming daily more and more a part of common education. In our cities now, and even in ordinary dwelling-houses, men are surrounded by prodigies of mechanic art, and cannot submit to use these, regardless of how they are produced, as a horse is regardless of how the corn falls into his manger. A general diffusion of knowledge, owing greatly to the increased intercourse of nations, and therefore to the improvements in the Physical departments of astronomy, navigation, &c. which favour that intercourse, is changing everywhere the condition of man, and elevating the human character in all ranks of society.

36. Sketch of the present world as improved by increase of Knowledge and Art.

In remote times, the inhabitants of the earth were generally divided into small states or societies, which had few relations of amity among themselves, and whose thoughts and interests were confined very much within their own narrow territories and rude habits. In succeeding ages, men found themselves belonging to larger communities, as when the distant parts of the British Isles became united; but still distinct kingdoms and quarters of the world were of comparatively little interest to them, and remained almost unknown. Now, however, every one feels that he is a member of the vast human family which covers the face of the earth; and no part of the earth is indifferent to him. In England, for instance, a man of small fortune, or almost any man whose industry and steady conduct provide him with good wages, may cast his looks around him, and say with truth and exultation, "I am lodged in a house that affords me conveniences and comforts which, some centuries ago, even a king could not command. Ships are crossing the seas in

every direction, to bring me what is useful to me from all parts of the globe. In China, men are gathering the tea-leaf for me; in America and elsewhere, they are planting cotton for me; in the West Indies, they are preparing my sugar and my coffee; in Italy, they are feeding silk-worms for me; in many places, they are shearing the sheep to make me clothing; at home, powerful steam-engines are spinning and weaving for me, and making cutlery for me, and pumping the mines, that minerals useful to me may be procured. Although my patrimony was small, or was only health and common education, I have mail-trains running day and night, on all the roads, to carry my correspondence; I have roads, and canals, and ships bringing coal for my winter fire; nay, I have protecting fleets and armies around my happy country, to secure all my enjoyments and repose. Then I have editors and printers, who daily send me an account of what is going on throughout the world, among all these people who serve me. And in a corner of my house I have Books! the miracle of all my possessions, more wonderful than the wishing-cap of the Arabian Tales; for they transport me instantly, not only to all places, but to all times. By my books I seem to conjure up before me, into vivid existence, many of the great and good men of antiquity; and I learn what they thought and did; the orators declaim for me; the historians recite; the poets sing." This picture is not overcharged, and might be much extended; such being the goodness and providence which willed this world into existence, that each individual of the civilized millions who inhabit it, when enlightened by knowledge and obeying the Divine precept of "do unto others as you would be done unto," may command the enjoyments it affords, almost as if he were the single lord of all.

37. Study of Natural Philosophy trains the mind better than that of mere Mathematics.

Reverting to the importance of Natural Philosophy as a general study, it may be remarked, that there is no occupation which so much strengthens and quickens the judgment. This praise has often been awarded to the Mathematics, although a knowledge of abstract Mathematics existed with all the absurdities of the dark ages; but a familiarity with Natural Philosophy, which includes fundamental Mathematics, and gives tangible and pleasing illustrations of the abstract truths, seems incompatible with the admission of any gross absurdity. A man whose

mental faculties have been sharpened by acquaintance with these exact sciences in their combination, and who has been engaged, therefore, in contemplating *real relations*, is more likely to discover truth in other questions, and can better defend himself against sophistry of every kind. We cannot have clearer evidence of this than in the history of the sciences, since the method of *reasoning by induction* took place of the visionary *hypotheses* of preceding times. Until then, even powerful minds did not recoil from the most absurd theories on all subjects. Astronomy was mixed with Astrology; Chemistry with Alchemy; Physiology with the singular hypotheses which preceded the discovery of the circulation of the blood; Politics with the errors of monopolies, prohibition, balance of trade, and so forth.

38. Even the state of Religion is much influenced by Men's knowledge of external nature.

Even Religion itself, in various ages and countries, has felt the influence of the state of the public mind as to knowledge of the visible works of creation. To a man with the knowledge of nature which we now possess, the fables and licentious abominations of the Greek or Roman theologies are shocking indeed; as are also the religions which have prevailed in China and over India, and Mahomet's imposture and pretended miracles, &c. The enlightened Christian minister highly approves of the study of nature; first, because from contemplating the beauty of creation, with the wisdom and benevolent design manifest in all its parts, there spring up in every undepraved mind those feelings of admiration and gratitude, which constitute the essence of natural religion, and, as represented by the esteemed writers on Natural Theology, these form a harmonious part and support of the still higher views which follow. There have been, however, at various times, even among Christians, sincere, but imperfectly informed men, who decried the study of the natural sciences, as inimical to true religion; as if God's ever-visible and magnificent revelation of his attributes in the structure of the universe could be at variance with any other revelation. But such prejudices are now quickly passing away. Wherever considerable knowledge of nature exists, debasing and gloomy superstition must cease. It is not the abject terror of a slave which is inspired by contemplating the majesty and power of the Creator, displayed in his works, but a sentiment akin to that which leads a favoured child to approach with confidence a wise and indulgent parent.

39. A few words respecting this Book.

It now only remains for the author to say a few words with respect to the present work. He was originally led to the undertaking with the view of supplying the desideratum in medical literature, of a treatise on *Professional Physics;* but soon perceiving that the preliminary investigation of *General Physics,* necessary to adapt the work to medical readers, would require to be nearly as extensive as if it were for general readers, and reflecting that every person of liberal education must now possess such a book, not to be read once and then thrown aside as a novel is, but to be frequently consulted as a manual, he determined to make his book as complete as he was able. He was encouraged, during his labour, by the belief, that the growing light of science, which now exhibits more clearly the natural relations of the different departments of study, as attempted to be portrayed in the preceding pages, might enable him to avoid some of the defects of former elementary treatises, and to add features of novelty and improvement to his own. The details here given in the sections on Animal Physics, are not more anatomical than the illustrations from the animal economy contained in the common treatises on *Natural Theology.*

40. Importance to students of assisting at experimental Lectures.

The author must not conclude without observing, that no treatise on Natural Philosophy can save, to a person desiring full information on the subject, the attendance on experimental lectures or demonstrations. Things that are seen, and felt, and heard, that is, which operate on the external senses, leave on the memory much stronger and more correct impressions than where the conceptions are produced merely by verbal descriptions, however vivid. And no man has become remarkable for his knowledge of Physics, Chemistry, or Physiology, who has not had *practical familiarity* with the objects. With reference to this familiarity, persons who take a philanthropic interest in the affairs of the world, must observe with much pleasure, the now daily increasing facilities of acquiring useful knowledge, afforded by the scientific institutions formed and forming, not only through this kingdom, but throughout all civilized nations.

ELEMENTS

OF

NATURAL PHILOSOPHY.

SYNOPSIS, OR GENERAL VIEW.

If it excite our admiration that a varied edifice, or even a magnificent city, can be constructed of stone from one quarry, what must our feeling be to learn how few and simple the elements are, out of which the sublime fabric of the universe, with all its orders of phenomena, has arisen, and is now sustained! These are a few general facts and laws which human sagacity has been able to detect, and then to apply to endless purposes of human advantage.

Now the four words, *atom, attraction, repulsion, inertia,* point to four general truths, which explain the greater part of the phenomena of nature. Being so general they are called *physical* truths, from the Greek word signifying *nature,* as also "truths of Natural Philosophy," with the same meaning, and sometimes "mechanical truths," from their close relation to all machinery. These appellations distinguish them from the remaining general truths, namely, the *chemical* truths, which regard particular substances, and the *vital* and mental truths, which have relation only to living beings. And even in the cases where a chemical or a vital influence operates, it modifies, but does not destroy, the physical influence. By fixing the attention then on these *four fundamental truths,* the student obtains, as it were, so many

keys to unlock, and lights to illumine the secrets and treasures of nature.

1st. Atom. Every material mass in nature is divisible into very minute indestruetible and unchangeable partieles,—as when a pieee of any metal is bruised, broken, cut, dissolved, or otherwise transformed, a thousand times, but can always be exhibited again as perfect as at first. This truth is conveniently reealled by giving to the partieles the name *atom*, which is a Greek term, signifying *that which cannot be farther cut or divided*, or an exceeding minute resisting partiele.

2nd. Attraction. It is found that the atoms above referred to, whether separate or already joined into masses, tend towards all other atoms or masses,—as when the atoms of whieh any mass is composed are, by an invisible influence, held together with a certain degree of foree ; or when a bloek of stone is similarly held down to the earth on which it lies ; or when the tides on the earth rise towards the moon. These faets are conveniently recalled by eonnecting with them the name *Attraction* (a drawing together), or *gravitation* (heaviness).

3rd. Repulsion. Atoms under eertain circumstances, as of heat diffused among them, have their mutual *attraction* countervailed or resisted, and they tend to separate or mutually to repel ;—as when iee heated melts into water, or when water heated bursts into steam, or when gunpowder ignited explodes. Sueh facts are eonveniently recalled by the term *Repulsion* (a thrusting asunder).

4th. Inertia. As a fly-wheel or grindstone made to revolve, at first offers resistance to the force moving it, but gradually acquires speed proportioned to that foree, and then resists being again stopped, in proportion to its speed, so all bodies or atoms in the universe have about them, in regard to motion, what has been figuratively called a *stubbornness*, tending to keep them in

their existing state, whatever it may be—in other words, they neither acquire motion, nor lose motion, nor bend their course in motion, but in exact proportion to some new force applied. Many of the motions now going on in the universe with such regularity—as that turning of the earth which produces the phenomena of day and night—are motions which were going on thousands of years ago, and continue unvarying in the way described. Such facts are conveniently recalled by the term *inertia* (or vis inertiæ) applied to them.

A person comprehending fully the import of these four words, that is to say, having present to his mind numerous good types or exemplars of the facts referred to by them, may prediet or anticipate correctly, and often may control for his purposes, many of the facts and phenomena, which the extended experience of a life will display to him; and such a person is eommonly said to know the eauses or reasons of things and events. But it is important here to observe, that when a person gives what is called a reason or explanation of any faet, other than that it is a fact, or than that the Creator has willed it, he is merely, although he may not be aware of this, pointing out its resemblance to many other facts, no one of whieh he understands better than itself;—and what he ealls a general truth, or law, or principle, is merely an expression for the observed but unaccounted-for resemblance of the facts. Thus, when a man says that a stone falls because of *attraction* or *gravitation*, he only uses a word which recalls thousands of instances whieh have been witnessed of bodies so falling or approaching one another; but any eause of the approaeh, other than that God has willed it, is to him as yet utterly unknown. Should men in the progress of their researches discover that the phenomena now classed by them under the heads of *attraction* and *repulsion*, although apparently opposite, are really as elosely allied as they already know the rising of a balloon and the falling of a stone to be (the balloon rises like a cork in water, because pressed up by a fluid air around it, which is heavier than it and seeking to descend), they will not have discovered a new eause, but a new re-

semblance, (new to them) among phenomena, and will only have advanced one step further in perceiving the simplicity of creation. In accordance with these views, it will be found that this volume is chiefly an extensive display of the most important phenomena of nature and art, classified so as to be explained by the four physical truths, and mutually to illustrate one another. They will be distributed under the following heads or divisions:

PART I.

THE FOUR FUNDAMENTAL TRUTHS.

These extensively illustrated by familiar examples, and used to explain generally, in

SECTION

1. The *nature or constitution of the material masses* which compose the universe; (a department technically called SOMATOLOGY, from Greek words signifying a *discourse* on *body*).*
2. The *motions* or *phenomena* going on among the masses;—a department including the common divisions of STATICS† (things stationary or at rest), and DYNAMICS‡ (what relates to *force* or *power*).

PART II.

PHENOMENA AMONG SOLIDS.

The four truths explaining the peculiarities of state and motion among *solid* bodies:—a department called, in a restricted sense, MECHANICS, (from the Greek word signifying *a machine.*)§

Animal Mechanics.—Phenomena in animal bodies.

PART III.

PHENOMENA AMONG FLUIDS.

The truths explaining the peculiarities of state and motion

* Σωμα, *Soma*, body. Λογος, *Logos*, discourse.
† Στατος, *Statos*, *stable*, standing still.
‡ Δυναμις, *dunamis*, power.
§ Μηχανη, *mechanè*, machine.

among *fluid* bodies:—a department called HYDRODYNAMICS (from Greek words signifying *water* and *force.*)

SECTION
1. HYDROSTATICS (*water at rest or in equilibrium*).*
2. PNEUMATICS (*air phenomena*).†
3. HYDRAULICS (*water or fluid in motion*).‡
4. ACOUSTICS (*phenomena of sound and hearing*).§
5. FLUIDITY in relation to animals.

PART IV.

PHENOMENA OF IMPONDERABLE SUBSTANCE.

The truths aiding to explain the more recondite phenomena of IMPONDERABLE SUBSTANCE, in four chapters.

CHAPTER
1. HEAT.
2. LIGHT.
3. ELECTRICITY (from the Greek word signifying *amber*; the electric light having been first obtained from amber):
4. MAGNETISM.

PART V.

PHENOMENA OF THE HEAVENS.

A department commonly called ASTRONOMY (from Greek words signifying *laws* of the *stars*). Αστηρ, aster, *star*. Νομος, nomos, *law*.

* Υδωρ, *udor*, water.
† Πνευμα, *pneuma*, breath, air.
‡ Αυλος, *aulos*, a pipe.
§ Ακουω, *akouo*, to hear.

THE APPENDIX

contains the outline of popular Mathematics, a Glossary, &c.

As no man well understands a subject of which he does not carry a distinct outline in his mind, it is recommended to the reader to study the general *synopsis*, and the *analyses* placed at the heads of the *chapters* and *sections*, until the memory be strongly impressed with them. The "*synopsis*" or outline gives a general view of the whole subject like what a traveller may obtain of a new country from a lofty central peak. The "*analysis*" gives a general view of one division, like what a traveller has of a portion of a country from a lower summit; and the "*heads*" placed thus between inverted commas, throughout the work, may be figured as stations commanding the view of single valleys or plains.

PART I.

THE FOUR FUNDAMENTAL TRUTHS EXAMINED, AND USED TO EXPLAIN GENERALLY, FIRST, THE NATURE OR CONSTITUTION OF THE MATERIAL MASSES WHICH COMPOSE THE UNIVERSE, AND SECONDLY, THE MOTIONS OR PHENOMENA GOING ON AMONG THEM.

SECTION I.—THE CONSTITUTION OF MATERIAL MASSES.

THE SUMMARY OR ANALYSIS OF THE SECTION.

The visible universe is built up of very minute indestructible ATOMS *called matter, which, by mutual* ATTRACTION, *cohere or cling together in masses of various form and magnitude. The atoms are more or less approximated according to the quantity or* REPULSION *of heat among them, and hence arise the three remarkable forms in masses, of solid, liquid, and air or gas, which mutually change into each other with change in the quantity of heat. Certain modifications of attraction and repulsion produce subordinate peculiarities of state called crystal, dense, hard, elastic, brittle, malleable, ductile, and tenacious.*

"*Minute Indestructible* ATOMS." *

1. THE smallest portion of any substance which the human eye can perceive, is still a mass of many ultimate atoms or particles, which may be separated from each other, or newly arranged, but which cannot individually be hurt or destroyed. This is deduced from such facts as the following:—

2. A particle of powdered marble, hardly visible to the naked eye, still appears to the microscope a block susceptible of indefinite division; and, when it is broken by fit means, until the microscope can hardly discover the separate particles of the fine powder, these may be yet farther divided, by solution in an

* The different heads or titles, which appear thus, throughout the work, between inverted commas, are the successive portions of the summaries or analyses, detached for separate consideration. The reader is particularly requested to re-peruse the analysis at the several interruptions, that he may have constantly before him that clear view of the general relations among the different parts of the subject, which is essential to a perfect understanding of it.

acid; the whole becoming then absolutely invisible, as part of a transparent liquid.

3. A small mass of gold may be hammered into thin leaf, or drawn into fine wire, or cut into almost invisible parts, or liquefied in a crucible, or dissolved in acid, or dissipated by intense heat into vapour; yet, after any and all of these changes, the atoms can be collected again to form the original mass of gold, without the slightest diminution or change. And all the substances or elements of which our globe is composed, may thus be cut, torn, bruised, ground, &c., a thousand and a thousand times, but are always recoverable as perfect as at first.

4. And, with respect to delicate combinations of these elements, such as exist in animal and vegetable bodies, although it be beyond human art, originally to produce, or even closely to imitate many of them—for we cannot build up a feather or a rose—still, in their decomposition and apparent destruction, the accomplished chemist of the present day does not lose a single atom. The coal which burns in his apparatus, until only a little ash remains behind, or the wax-taper which seems to vanish altogether in flame, or the portion of animal flesh which putrefies, and gradually dries up and disappears—presents to us phenomena which are now proved to be only changes of connection and arrangement among the indestructible ultimate atoms; and the chemist can offer all the elements again, mixed or separate, as desired, for any of the useful purposes to which they are severally applicable. When the funeral piles of the ancients, with their charge of human remains, appeared to be wholly consumed, and left the idea with survivors that no base use could be made, in after time, of what had been the material dwelling of a noble or beloved spirit, the flames had only, as it were, scattered the enduring blocks of which a former edifice had been constructed, but which were soon to serve again in new combinations.

5. Facts, to be stated under the heads of "chemical composition" and "crystal," lead to the conclusion, that the ultimate particles of any substance are, among themselves, perfectly similar.

"*Minute.*" (Read the Analysis, page 7.)

The following are interesting particulars in the arts or in nature, helping the mind to conceive how minute the ultimate atoms of matter must be.

7. Goldbeaters, by hammering, reduce gold to leaves so thin,

that 360,000 must be laid upon one another to produce the thickness of an inch. Eighteen hundred of them occupy only the space of a single leaf of common paper; yet they are so perfect, or free from holes, that one of them laid upon any surface, as in gilding, gives the appearance of solid gold.

8. Still thinner than this is the coating of gold, upon the silver wire of what is called gold lace; and we know not that such coating is of only one atom thick. If we place a piece of such wire in nitric acid, so as to dissolve the silver from within, the gold coating remains as a metallic tube of exquisite tenuity.

9. Platinum can be drawn into wire much finer than human hair.

10. A grain of blue vitriol, or carmine, will tinge a gallon of water, so that in every drop the colour may be perceived.

11. A grain of musk will scent a room for twenty years, and will have lost but little of its weight.

12. The carrion crow seems to smell its food at a distance of miles.

13. The thread of the silk-worm is so small, that many folds have to be twisted together to form a sewing thread; but that of the spider is smaller still, for two drachms of it by weight would reach from London to Edinburgh, or 400 miles.

14. In the milt of a cod-fish, or in water in which certain vegetables have been infused, the microscope discovers animalcules, of which thousands together do not equal in bulk a grain of sand; yet, these have their blood and other component parts like larger animals; and indeed nature, with a singular prodigality, has supplied many of them with organs as special as those of the whale or elephant. Now the body of an animalcule consists of the same elementary substances, or ultimate atoms, as the body of man himself. In a single pound of matter, it thus appears, that there may be more living creatures than of human beings on the face of this globe. What scenes has the microscope laid open to the admiration of the philosophic inquirer!

15. Water, mercury, sulphur, or, in general, any substance, when sufficiently heated, rises as invisible vapour or gas; in other words, is made to assume the aëriform state. Great heat, therefore, would cause the whole of the material universe to disappear, the previously most solid bodies becoming as invisible and impalpable as the air we breathe. Utter annihilation would seem but one stage beyond this.

"*Matter.*"

16. The inconceivable minuteness of ultimate atoms, as shown above, has led some inquirers to doubt whether there really be *matter ;* that is to say, whether what we call the substance or matter of the universe, have positive permanent existence or not. In answer to this, it has been usual to adduce, besides the weight of the substances, and the proofs of indestructibility already mentioned, which seem conclusive, the fact, that every kind or portion of matter obstinately occupies some space, to the exclusion of all other matter from that particular space. This occupancy of space is the simplest and most complete idea which we have of material existence. The awkward word *impenetrability* has been used to express it, with reference of course to the individual atoms. The following are elucidations.

We cannot push one billiard-ball into the substance of another, and then a second, and then a third, and so on ; or the material of the universe might be absorbed in a point.

A mass of iron on a support can resist the weight of thousands of pounds laid upon it and pressing to descend into its place; and although a very great weight may crush or break it into pieces, still not one particle would be annihilated.

In a forcing-pump, or in Bramah's water-press, millions of pounds cannot push the piston down, unless the water below it be allowed to escape.

A weight laid upon bladders full of air, or on the piston-handle of an air-pump closed below, is supported in the same manner.

A quantity of air escaping from a vessel under water ascends through the water as a bubble, displacing its bulk of water in its way.

17. A glass tube, left open at bottom, while the thumb closes the top, if pressed from the air into water, is not thereby filled with water, because the air contained in it resists; but if the air be allowed to escape by removing the thumb from the top, the tube becomes filled immediately to the level of the water around it. In a goblet or basin pushed into water, with the mouth downwards, the entrance of water from below is resisted for the like reason; and if the goblet be inverted over a floating lighted taper, this will continue to float under it, and to burn in the contained air, however deep in the water the goblet be carried—exhibiting the curious phenomenon of a light below

water, and being an emblem of the living inmate of a diving bell, which is merely a larger goblet holding a man instead of a candle.

"*Mutual* ATTRACTION." (See the Analysis, page 7.)

18. Any visible mass of matter, then, as of metal, salt, sulphur, &c., we know to be really a collection of dust, or minute atoms, by some cause made to cohere or cling together; yet there are no hooks connecting them, nor nails, nor glue; and the connexion may be broken a thousand times, by processes of nature or art, but is always ready to take place again; the cause being no more destroyed in any case by interruption, than the weight of a thing is destroyed by frequent lifting from the ground. Now the immediate cause we as yet know not, but we call it *attraction.*—The phenomena of attraction and its contrary, *repulsion,* particularly when occurring between bodies at considerable distances from each other, appear as little explicable as any subjects which the human mind has to contemplate; but the manner or laws of the phenomena are now well understood. The general nature and extensive influence of attraction may be judged of from the following facts:—

19. Bodies floating in water obey the slightest moving force. This is seen when children amuse themselves by watching the motions produced by mutual attraction among floating stalks of tea in a tea-cup, or chips of wood in a basin; they quickly run together, or to the sides of the vessel, and if then pushed away, they again approach as energetically almost as if they were alive. Although the fact of attraction is hereby well illustrated, the case is not so simple as in the other instances which follow.

20. Two bullets or plummets suspended by strings near to each other, are found by the delicate test of the torsion balance (described hereafter) to attract each other, and therefore not to hang quite perpendicularly.

21. A plummet suspended near the side of a mountain inclines towards it, in a degree dependent to its magnitude; as was ascertained by the well-known trials of Dr. Maskeleyne near the mountain Schehallion, in Scotland.

And the reason why the plummet in such a case tends much more strongly towards the earth than towards the hill, is only that the earth is larger than the hill.

At New South Wales, which is situated on our globe nearly opposite to England, plummets hang and fall towards the centre

of the globe, as they do here; so that, in respect to England, they are hanging and falling upwards, and the people there, like flies on the opposite side of a pane of glass, are standing with their feet towards us,—hence called our antipodes. Weight, therefore, is merely general attraction acting everywhere.

22. But it is owing to this general attraction that our earth itself is a globe: all its parts being drawn towards each other, that is, toward a common centre, the entire mass assumes the spherical or rounded form.

And the moon also is round, and all the planets; nay the glorious sun too, so much larger than these, is round;—suggesting the inference that the substance of all has taken form under the influence of the same law.

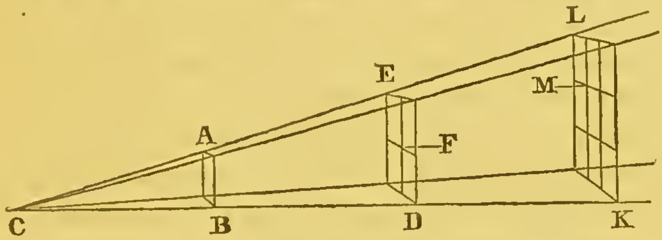
23. Returning to the earth and its more minute masses, we have to observe many interesting instances of roundness from the same cause; as—the particles of a mist or fog floating in air—these, mutually attracting and coalescing into larger drops, and so forming rain—dew-drops—water trickling on a duck's wing—the tear dropping from the cheek—drops of laudanum—globules of mercury, like pure silver beads, coalescing when near, and forming larger ones—melted lead allowed to rain down from an elevated sieve, and by cooling as it descends so as to retain the form of its liquid drops, becoming the beautiful shot-lead of the sportsman, &c.

24. The cause of the extraordinary phenomenon which we call attraction, acts at all distances. The moon, though 240,000 miles from the earth, by her attraction, raises the water of our ocean under her, and causes what we call the tide.—The sun, still farther off, has a similar influence; and when the sun and moon act in the same direction, we have the spring tides.—The planets, so distant that their vast masses appear to us but little wandering points in the heaven, yet, by their attraction, affect the motion of our earth in its orbit, quickening the motion when the bodies are approaching, retarding it when they are receding.

25. The *attraction is greater* the nearer the bodies are to each other; just as the light of a candle is more intense nearer to the candle than at a distance.

26. A board of a foot square, represented in this figure by A B, at a certain distance from a light, supposed at C, just shadows a board of two feet square, as E D, at double distance, and a board of three feet square, as I K, at triple distance, and

so forth; but a board with a side of two feet has four times as much surface as a board with a side of one foot, for it is not only twice as high or long, which would make it double, but twice as broad also, which makes it quadruple—or as a globe



of two feet diameter requires just four times as much paper to cover it as a globe of one foot: and the corner, or fourth part, E F, of the larger square here shown is just equal to the whole of the smaller square A B. Light, therefore, at double distance from its source, being spread over four times the space, has only one-fourth of the intensity; and for a similar reason, at thrice the distance it has only a ninth part, at four times a sixteenth part, and so on. Now light, heat, attraction, sound, and indeed every influence spreading uniformly from a central point, is found to decrease in the proportions here illustrated, *viz.* as the surface of squares which shadow one another increases. The technical expression is, "*the intensity is inversely as the square of the distance;*" (the distances being estimated from the centres of attraction or radiation) or is one-fourth part as strong at double distance, four times as strong at half distance, and in a corresponding manner for all other distances.

Accordingly what weighs 1000 lbs. at the level of the sea weighs considerably less at the top of a mountain, or when raised in a balloon—as is proved experimentally by a spring balance, or other means;—and at the distance of the moon, the weight, or attraction towards the earth, is diminished still in the same proportion, as is proved by astronomical tests.

ATTRACTION has received different names, as it is found acting under different circumstances. The chief distinctions are *Gravitation, Cohesion, Capillary, Chemical, and Electrical attractions.*

Gravitation is the name given to it when acting at sensible distances, as in the cases of the moon lifting the tides —the sun and earth attracting each other—a stone falling, &c. Most of the facts enumerated at page 11, belong to this head.

27. *Cohesion* is the name given, when it is acting at very short distances, as in keeping the atoms of any mass together.

It might appear that it cannot be the same cause which draws a mass of iron down to the earth and holds it there with the moderate force called its weight, and which also keeps together the constituent atoms of iron in such strong cohesion, as in the form of a cannon ball or of a length of wire; but science cannot yet speak decidedly on the subject. Attraction is stronger as the substances are nearer to each other, and atoms almost in contact may be a thousand times nearer than when only a quarter of an inch apart.

28. If the surfaces of bodies, even of those deemed smooth, were not in general really so rough and irregular, that when applied to each other they can touch only in a few points of the million or more which each surface contains, bodies would frequently be found sticking together or cohering from accidental contact. The effect of artificially smoothing and planing touching surfaces is seen in the following examples.

Similar flat-faced portions being cut off with a clean knife from two leaden bullets, and the fresh surfaces being brought into contact with a slight turning pressure, the bullets cohere, almost as if they had been originally cast in one piece.

Fresh-cut surfaces of India-rubber or caoutchouc cohere in a similar way. If a sheet of India-rubber be folded double, and a strip be then cut off by one stroke of a pair of long scissors near the fold, that strip is found to be a perfect tube with a seam scarcely visible. The freshly-cut surfaces being in contact under strong pressure at the instant of division cohere at once.

Two pieces of perfectly smooth plate-glass or marble, laid upon each other and compressed, may adhere with such force, that they cannot again be separated without fracture. Other well-polished flat surfaces placed in contact exhibit degrees of the same phenomenon.

29. Cohesion between a solid and liquid, and between the particles of a liquid among themselves, is seen in the following instances.

A flat piece of glass, balanced at the end of a weighing beam, and then allowed to come into contact with water, adheres to the water, and with much more force than the weight

of water remaining upon it when again forcibly raised. If there were not cohesion or attraction of the water particles among themselves, as well as to the glass, the latter could be held down only by the weight of the water which directly adhered to it.

30. In pouring water from the lip of a mug or cup, the water does not at once fall perpendicularly away from it, but runs for a little way along the inclined outside of the vessel, owing to the attraction between that and the water; hence the difficulty of pouring from a vessel which has not a projecting lip.

A finger dipped into water and then withdrawn is wetted, because there is attraction between the skin and water, but if dipped into quicksilver it comes out clean and dry, because there is not the mutual attraction; but a piece of silver or gold immersed in mercury comes out covered with mercury adhering to it, and might be said to be moistened with mercury.

The particles of water cohere among themselves in a degree which causes small needles gently laid on the surface to float; the weight of the needles not being sufficient to overcome the cohesion of the water surface.

For the same reason many light insects can walk upon the surface of water without being wetted.

31. It is chiefly the different force of the attraction of cohesion in different liquids that causes their drops or gutts from the lip of a phial to be of different magnitude. Sixty drops of water fill the same measure as 100 drops of laudanum from a lip of the same size.

32. In any large mass of liquid on earth, the attraction which, if acting alone, would draw the particles into the form of a distinct small globe, yields to the greater attraction which draws them all towards the centre of the earth, and therefore the liquid assumes, more or less completely, what is called a level surface, that is, a surface corresponding with the general surface of the earth.

Attraction is called *capillary** when it takes place between a liquid and the interior of a solid which is porous.

33. When one end of any open glass tube is immersed in water, the water which enters it rises somewhat above the level of that on the outside. The difference of level is greater as the tube is smaller, because, in small tubes, the glass all round is

* A name originally given because the phenomenon was noticed in small glass tubes scarcely larger than hairs (capillus).

nearer to the column of raised water within, and attracts it more powerfully.

34. Between two plates of glass standing near to each other, with their lower edges in water, a similar rising of water will occur; and if the plates are nearer together at one perpendicular edge than at the other, the surface of the suspended water will be higher there. The two plates of glass in such a case are found to be drawn towards each other by the cohesive attraction of the interposed waters, as happens also to glass beads, or other small bodies, floating in water when their surfaces come near to each other.

35. Water, ink, or oil, coming in contact with the edges of a book, is rapidly absorbed far inwards among the leaves.

A piece of sponge or a lump of sugar touching water by its lowest corner, soon becomes moistened throughout.

The wick of a lamp thus lifts the oil to supply the flame, from two or three inches below it.

A mass of cotton thread hanging over the edge of a glass from the water within it will empty it, nearly as a syphon would. The corner of a towel will empty a basin of water in the same way.

Dry wedges of wood driven into a groove formed round a pillar of stone near one end, on being moistened, will swell so as to rive off the portion from the block. In some quarries (of Germany) millstones are thus cut from the rock.

A great weight or mass suspended by a dry rope may be raised a little way, by merely wetting the rope:—the moisture imbibed by capillary attraction into the substance of the rope causes it to swell laterally and to become shorter.

At one time the small vessels of vegetables were supposed to raise the sap from the roots, solely by capillary attraction; but this is known now to be a more complex function of vegetable life.

Attraction has received the name of *chemical attraction*, or *affinity*, when it unites the atoms of two or more distinct kinds of substance into one perfect compound.

36. There are about sixty substances in nature which appear, in the present state of science, distinct from each other, and are therefore called *kinds of matter:* such as, the various metals, sulphur, phosphorus, carbon, oxygen, hydrogen, &c.; but whether these are, in truth, originally and essentially dif-

ferent, or are all only one simple primordial matter, modified by circumstances as yet unknown to us, we cannot at present positively determine. Diamond and pure black charcoal are the same substance, only with different arrangement of the atoms; and steel, which in the soft state can be cut by the graver as easily as copper or silver, is exactly the same substance as when, after being tempered by heating and sudden cooling, it has become as hard nearly as diamond itself. And yet these differences are more striking than ever appear between some substances, which are now accounted essentially distinct.

37. It is found, however, that the atoms of what we call different substances will not cohere and unite indifferently, to form masses, as atoms of the same kind do,—there being among them singular preferences and dislikes, if it may be so expressed, or affinities as the chemists term it; and when atoms of two kinds do combine, the resulting compound generally loses all resemblance to either of the elements.—Thus:

38. Sulphuric acid will unite with copper and water, and form a beautiful translucent blue salt; with iron it will form a green salt; and if a piece of iron be thrown into a solution of the copper salt, the acid will immediately let fall the copper, and take up or dissolve the iron.—Sulphuric acid will not unite with or dissolve gold at all.—Quicksilver and sulphur unite in certain proportions and form the paint called vermilion; in other proportions they form the black mass called Ethiops Mineral. —Lead with oxygen absorbed from the atmosphere or other source forms what is called red lead, used by painters.—Sea-sand, or flint, and the substance called soda, when heated together, unite and form that most useful substance called glass. —Certain proportions of sulphur and of iron combine and produce those beautiful cubes of pyrites, or gold-like metal, which are seen in slate.—Chemical attraction operating thus, does not in the slightest degree interfere with general attraction or gravitation, for every chemical compound weighs just as much as its elements taken separately.

39. The reader has to note here the all-important difference between the merely mechanical mixture of elements, as of fine sand and powdered soda, which might lie together unchanged for centuries, and the chemical union of the two into transparent homogeneous glass, which union is produced by melting them together through the influence of strong heat.

40. The history and classification of the facts connected with

the combinations and decompositions of different substances, constitute the comparatively new science of chemistry, now become so attractive because so useful; which explains how the sixty kinds of matter above alluded to, by variously combining, form the endless diversity of bodies which build up, as far as it has yet been explored, the mass of our globe. This fact is analogous to that other, of the nearly same number of simple sounds, indicated by the letters of one general alphabet, sufficing, when differently grouped, to form all the words of all the languages on earth. The reason of the various modifications of chemical attraction are yet hidden from us.

41. It is a remarkable fact, that when different substances combine chemically in the way above described, the proportions of the ingredients are always uniform, and such as lead to the conclusion, that in a compound particle, for one atom present of some one substance, there must be exactly one, or two, or three, of the other or others, but never a broken number, as if a particle of the compound could consist of one atom of the first, and one and a fraction of the second substance. Many elementary substances seem to unite with each other only in one proportion, as of one to one, and so to form only one compound: but others unite in several proportions, as of one to one, or one to two, one to three, &c.; so that several distinct compounds arise out of the same two elements.

42. It thus appears, that although we do not know the exact number of atoms in a given quantity of any compound substance,—whether, for instance, a grain of vermilion has more or less than a million of them; still if we know that in that grain there are just as many atoms of sulphur as of mercury, and that the weight of the whole sulphur is to that of the whole mercury as four to twenty-five, we know that the single atoms must have the same relation, or that the atom of mercury is $6\frac{1}{4}$ times as heavy as that of sulphur.

Tables have been formed exhibiting the relative weights of the atoms of the different elementary substances; and the number standing opposite to each substance is called its *chemical equivalent*,—that is to say, the weight of its atom in relation to the weight of the atom of some other substance chosen as a standard. The *equivalent* of a compound particle depends of course on the equivalents of the ingredients, and on the number of atoms of the ingredients existing in an integrant particle of the compound.

It would be incorrect to speak of an *atom* of vermilion, or of any other compound, for the ultimate molecule or particle must contain at least one atom of each of the respective ingredients.

43. The fact of the peculiarities and constancy of chemical unions are among the strongest arguments for the opinion that the ultimate atoms are similar and immutable.

BESIDES the various cases of attraction above treated of, there are important forms, called *electrical* and *magnetical* attractions with corresponding repulsions, which, from their peculiarities, are reserved for consideration in a future division of this work.

"*Masses of various form and magnitude.*" (See the Analysis.)*

"*Atoms or particles are more or less close and coherent, according to the quantity or* REPULSION *of heat among them; hence the forms of solid, fluid, air, &c.*" (Read the Analysis, p. 7.)

44. Were there in the universe only atoms and attraction, as hitherto explained, the whole material of creation would rush into close contact, forming one huge solid mass of stillness and death. But there is also heat, at one time called caloric, which counteracts attraction, and singularly modifies the results. It has been held by some to be a most subtle fluid, pervading all things, somewhat as water pervades a sponge; others have accounted it merely a vibration or motion among the particles. The truth is, that we know little more of heat as a cause of repulsion, than of gravity as a cause of attraction: but we can study and classify most accurately the phenomena of both.

45. When a continued addition of heat is made to any body, it gradually, as the general result, increases the mutual distance of the constituent particles, or dilates the body. A solid thus is first enlarged and softened; then melted or fused, that is to say, reduced to the state of liquid, as the cohesive attraction is overcome; and lastly, the atoms are repelled to still greater distances, so that the substance is converted into gaseous fluid or air. Abstraction of heat from such air causes return of these states in the reverse order.

* This subject is considered in the APPENDIX under the title of *Elementary, or Popular Mathematics.* The reader is advised to refer to it, whenever a question of measuring is not extremely simple.

46. Thus ice when heated becomes water, and the water when farther heated becomes steam: the steam when cooled again becomes water as before, and the water when cooled becomes ice. Ice, water, and steam, therefore, are three forms or states of the same substance—one of the most common in nature, for it is the chief material of the ocean.

Other substances are similarly affected by heat, but as all have different relations to it, some requiring much for liquefaction, and some very little, we have that beautiful variety of solids, liquids, and airs, which constitutes our external nature.

47. *Dilatation.*—A rod of iron, which, when cold, will just pass through a certain opening in another piece of iron, and will lie lengthwise between two fixed points, when heated, becomes too thick and too long to do either.—For accurate mensuration, therefore, rods or chains used as the measure, must either be at a given temperature, or due allowance must be made for the difference.

48. The walls of a building in Paris, under the pressure of a heavy roof, had begun to bulge out so as to threaten its stability. No force tried was sufficient to restore them to perpendicularity, until the idea occurred of using the contracting force of cooling iron. The opposite walls were then connected by a number of iron bars, passing through both, and having nuts upon their projecting ends to screw close to the wall. Of these bars one-half were heated at a time, *viz.*, every second or alternate bar, by lamps placed under them, and while lengthened in consequence, and projecting farther beyond the wall, the nuts on them were again screwed close up, and on cooling and contracting, they pulled the wall back to its place.

49. The iron rim or tire of a coach-wheel, when heated, goes on loosely and easily, but when afterwards cooled, it binds the wheel most tightly, giving the remarkable firmness and strength which such a wheel is known to possess.

Iron hoops on ships' masts and on casks are made to bind in a similar manner.

50. The common thermometer for measuring degrees of heat, is a glass bulb filled with mercury or other fluid, and having a narrow tube rising from it, into which the fluid, on being expanded by heat, ascends, and so marks the degree.

A bladder not quite full of cold air, on being heated becomes tense, and if not strong may burst.

51. *Liquid and Air or Gas.*—A piece of gold, lead, pitch, ice,

sulphur, or other thing, if sufficiently heated, melts or becomes liquid; each substance, however, requiring a different degree of heat—gold requires 5,000 degrees, lead 600, ice 32, and so forth; and if the heating be afterwards continued, most things at certain higher temperatures suddenly expand again to many times the liquid volume, and become aëriform or gaseous fluids.

The conversion of water into steam is familiarly known to all. One pint of water driven off as steam from the boiler of a low-pressure steam-engine, fills a space of nearly 2,000 pints, and raises the piston through this space, with a force of many thousands of pounds: it immediately afterwards appears again in the cold condenser as a pint of water.

52. Six times as much heat is required to convert a pint of water into steam, as to raise it from freezing temperature to that of boiling; but the steam by occupying nearly 2,000 times the space of the water, is held to prove that heat merely produces a repulsion among the particles, and does not fill up the interstices. The steam rising from boiling water, although carrying away so much heat, does not appear to the thermometer hotter than the water itself; and hence it was that Dr. Black, whose genius shed so much light on this part of knowledge, gave to the excess of heat the name of *latent heat.*

53. The latent heat of common air is made sensible in the *match syringe.* In this, which is a tube close at the bottom, the piston is driven down quickly and strongly, so as to compress very much the air which is underneath it, and the heat then condensed with the air is sufficiently intense to light a small piece of tinder attached to the bottom of the piston.

Not only are spirits, æthers, oils, &c., convertible, as water is, into aëriform fluid, but also sulphur, phosphorus, mercury, and indeed all the metals and elementary substances;—some of them, however, requiring heats of great intensity.

54. The varieties of form, then, in the bodies on the face of this earth, may be called accidental, as dependent on the temperature of the earth, and do not mark the permanent nature of the substances.

In the planet Mercury, which is near the sun, resin, tallow, wax, and many vegetable substances deemed by us naturally solid, would all be liquid, as oil is with us; and a certain mixture of tin, zinc, and lead, which with us is solid at common temperatures, but melts in boiling water, would there be always

liquid like our quicksilver. Our water, oils, and spirits, would there be in a state of steam or air, and could not be known as liquids, except by cooling processes and compressions, such as we have lately learned to use for reducing different airs to the form of liquids.

Again, in the cold planet Uranus, which is nineteen times farther from the sun than our earth is, water, if it exist, can be known only as a rock crystal, which fire would have to melt as it does glass with us: our oils would be as butters or resins, and quicksilver might be hammered, as lead or silver is with us.

On our own earth, near the equator, common sealing-wax will not retain impressions; butter is oil in the day, and a soft solid at night; and tallow candles cannot be used. And near our pole, in winter, the quicksilver from a broken thermometer is solid metal; water must be melted by fire for use; oils are solid, &c.

55. To judge then of the constitution of nature aright, we must take extended surveys, and not allow narrow knowledge or prejudice to mislead us, as is recorded to have happened to an Eastern prince who treated a European traveller as an impostor for saying that in his country during the cold season the surface of the rivers or ponds became solid like glass, so that men could walk upon them.—The ancients believed that there were just four elements concerned in forming our globe, with all upon it, namely, *earth*, *water*, *air*, and *fire*. What a contrast between former and present knowledge!

Repulsion without sensible Heat.

56. As we stated in a former paragraph that, besides general attraction, under the names of *gravitation*, *cohesion*, *capillary*, and *chemical attraction*, there are modifications which have the names of *electrical* and *magnetical* attractions; so we have now to remark, that, besides the general repulsion of heat just described, there are peculiarities which we call *electrical* and *magnetical repulsions*. Whether these depend altogether on different causes, or are only modifications of effect from the same cause, is not yet decided.

57. And it is a curious fact connected with the subject, that there seems to be a film of repulsion, so to express it, covering the general surfaces of bodies, and preventing their meeting in absolute contact, even when they appear to the human eye so to meet. Were it not for this, things would be often

approaching so near to each other, that they would stick or cohere, in a way to disturb the common operations of nature. The following facts illustrate this superficial repulsion, and the means which art uses to overcome it for particular purposes.

58. Newton, during experiments on light, found that a convex lens, or a watch-glass, laid upon a flat surface of glass, does not really touch it, and cannot be made to touch it by a force of many pounds to the inch.

In like manner, when glass, stone, porcelain, or indeed almost any body is broken, we cannot make the parts cohere again by simply pushing them together in their former position. Where a union therefore between separate masses is desired, we are compelled to have recourse to various artifices.

A few cases in which cohesion is easily effected were enumerated at page 14: the following are other instances of a different kind.

59. Gold leaf laid upon clean steel, and then forcibly struck by a hammer, coheres to the steel, and gilds it permanently.

But iron can be made to cohere to iron, only by rendering both pieces red hot before hammering:—the process is called welding. Iron and platinum are the only metals that can be welded.

Tin and lead in sheets, if strongly pressed together between the rollers of a flatting-mill, cohere.

The other metals require to be melted before the superficial repulsion gives way and allows separate quantities to cohere or run into one mass. It is thus, for instance, that gold, silver, lead, &c., are treated.

60. In many cases the substances are not such as can be melted (wood or marble, for instance), and then it is necessary to use some soft cement—as glue. Cements must have strong attraction for both substances, and must, when dry or cool, be tenacious in themselves; solder, paste, common glue, mortar, &c., are the principal substances of this kind.

"*Certain modifications of attraction produce, in solids, the subordinate states, called crystal, porous, dense, &c.*" (Read the Analysis, page 7.)

61. Although the pressing together with *moderate* force does not cause ordinary solids to cohere, it has lately been found that *very strong* compression does instantly produce the effect. Brick dust is thus formed into tiles, agate dust into agate buttons,

broken ice into solid lumps, &c. And thus in part it is explained why sand and other such comminuted matter deposited at the bottom of the sea, and undergoing there the pressure of great depths of matter, is formed into the cohesive sandstone, or other kind of rock, which, when upheaved, men use in architecture.

62. It is a remarkable circumstance, that attraction, in causing atoms or particles to cohere so as to form solid masses, seems not to act equally all around each atom, but between certain sides or parts of one, and corresponding parts of the adjoining ones; so that when they are allowed to cohere according to their natural tendencies, they often assume a certain regular arrangement and form, which we call crystalline. Because in this circumstance they seem to resemble magnets, which attract each other chiefly by their poles; the fact has been called the polarity of atoms. It is the cause of several of the peculiarities above enumerated, as elasticity, &c.

"*Crystallization*" is exemplified in the following particulars:

63. Water beginning to freeze, shoots delicate needles across the surface; these thicken and join until the whole mass has become solid, but the crystalline arrangement always remains. In most substances this arrangement is remarkably proved, by the forms of the surfaces left, when the mass is broken.

Moisture freezing on the window-pane in winter, exhibits a beautiful variety of arborescence.

64. A flake of snow, viewed in the microscope, is seen to be as symmetrically formed as a fern leaf or a bird's feather.

65. If a piece of copper be thrown into a solution of silver in nitric acid, it is preferred by the acid to the silver, and is dissolved accordingly, while the silver is rejected: the silver in the mean time, during its precipitation or separation, assumes the form of a singularly beautiful shrub or tree, resting on the remaining copper as its root. This formation is called the *arbor Dianæ*.

66. Any metal which has been melted, when allowed to cool again, slowly and at rest, becomes solid first on the outside of the mass. If, before the cooling be completed, the remaining liquid be poured from within, a curious internal crystalline structure, like grotto-work, is seen. What is called the grain of a metal is the result of this crystallization.

67. Saltpetre, glauber salt, copperas (to use popular names), or any other of the many neutral salts, being dissolved in water,

and the water being then allowed slowly to evaporate, re-appears in beautiful solid crystals, each salt having its peculiar forms, bounded by perfectly plane and polished surfaces. If any such crystal be broken in any part, the broken surface appears to tho microscope as if regular layers of particles had been disturbed (as we see on a larger scale in a broken stack of bricks, or broken pile of bullets in a battery yard), and the defect of the crystal will be exactly filled up by replacing it in the evaporating solution—proving to the judgment of many that the ultimate particles are all of the same size.

All the precious stones are crystals, and can be well cut and polished only parallel to their natural faces.

The basaltic pillars of the Giant's Causeway in Ireland, and of the Isle of Staffa, which appears like a garden supported on magnificent columns in the midst of the ocean, are natural crystalline arrangements of particles, rivalling in regularity and beauty any human work, and in grandeur so far surpassing, that superstitious conjecture might suppose them the work of giant architects.

It would be endless to go on enumerating crystalline masses, for nature's forms generally, in the inanimate creation, as well as in organized bodies, are more or less regular and symmetrical; and what we see on earth of broken continents, and islands, and rocks, and wild alpine scenery, are the effects of subsequent agencies which deranged a former more simple order.

Much ingenuity has been employed to account for the specific forms which different crystalline bodies assume; but the subject is not yet reduced to a state fitting it to be a part of elementary study. A familiarity with the various figures, which the exact *science of measures* treats of, is required in the person who expects to pursue it with pleasure or advantage.

68. "*Porous.*"—The crossing of the constituent needles or plates in bodies, may cause them to be porous or full of small vacant spaces. In some cases these are visible to the eye; in other cases, they are visible to the microscope; and in all, they are to be proved in some way.

69. The fact that there is no body, solid, liquid, or aeriform, which may not be lessened in bulk by compression, is explained by supposing the atoms or particles not to be in absolute contact, but held near to one another by balancing forces of attraction and repulsion, modified by temperature, &c. The ready

passage of light through such solid masses as glass and diamond leads to the same conclusion.

70. Owing to porosity or new arrangement of atoms taking place on solidifying, water and a very few other substances become more bulky in the change from the liquid to the solid state. Water then dilates with such force, as to burst the strongest vessels which art can provide, and in winter to split even rocks, where it has been retained in their crevices;—freezing water thus curiously producing effects equal to those of exploding gunpowder. This agency of water contributes to the gradual breaking down of our alpine summits, and the destructive falling of their fragments into the valleys.

The stone called hydrophane (agate) is opaque, until dipped into water, when it absorbs into its pores one-sixth of its weight of the water, and afterwards gives passage to light.

Into crystallized sugar, and various stones, much water will enter without increasing the bulk.

A kind of sand-stone, suitably shaped, forms an excellent filter or strainer for water. It allows the water itself to pass, but detains the solid impurities.

71. Pressure will force water through the pores of solid gold;—as was seen in the famous Florentine experiment, where a hollow, thick, golden ball, being filled with water and squeezed, to prove the compressibility of water, was found to perspire all over.

The amount of pores in animal and vegetable bodies are, however, the most remarkable.

Bone is a tissue of cells and partitions, as little solid as a heap of empty packing-boxes.

Wood is a congeries of parallel tubes, like bundles of organ pipes. Wood has lately been prepared for certain purposes, as for making the wooden pins used in ship-building, by squeezing it between very strong rollers to half its lateral bulk, and thus making its density approach to that of metal.

72. A piece of wood sunk to a great depth in the ocean, and exposed to the pressure there, has its pores soon filled with water, and becomes nearly as heavy as stone. Thus it was with the boat of a whale-fishing ship, which had been dragged far under water by a whale, and which, on being afterwards drawn up by the rope of the harpoon, was supposed to be bringing a piece of rock with it.

73. A piece of cork in a strong glass vessel nearly full of water, may be seen floating at the top; but if more water be then forcibly pumped into the vessel, the cork will be gradually squeezed and reduced in size, until at last it is heavier than water and sinks. On water being afterwards allowed to escape, the cork will resume its bulk and rise. A cork sunk 200 feet in water, will never rise again of itself.

74. A bottle of fresh water, corked and let down thirty or forty feet into the sea, often comes up again with the water saltish, although the cork be still in its place: the explanation being, that the cork, when far down, was so squeezed as to allow the water to pass in or out by its sides, but on rising resumed its former size.

75. "*Density*," or the quantity of particles which exist in a given space, is very different in different substances.

76. A cubic inch of lead is forty times heavier than the same bulk of cork. Mercury is nearly fourteen times heavier than an equal bulk of water.

The density must depend on, first, the weight of the individual atoms; secondly, the degree of porosity as just explained; and thirdly, the proximity of the atoms in the more solid parts which may stand between pores.

A body dilates or contracts, according as heat is added to or taken away from it.

A weight placed on any upright rod or pillar, shortens it and lessens its bulk, and if suspended from the bottom, lengthens it and increases its bulk,—the rod in both cases returning to its former dimensions when the weight is removed.

When a plank or rod is bent, the atoms on the concave side are for the time approximated, and those on the convex side are drawn more apart. It is remarkable in solid bodies, not only how precisely the balance between attraction and repulsion determines the relative position of the particles, but also how strongly; for any farther separation of the particles is resisted by all the force which we call the tenacity or cohesion of the substance, and any nearer approach by all the force which we call the hardness or resistance to compression.

77. Tin and copper when melted together to form bronze, occupy less space by one-fifteenth than when separate: proving that the atoms of the one are partially received into what were vacant spaces in the other. A similar condensation is observed

in many other mixtures. A pound of water and a pound of salt, when mixed, form two pounds of brine, but which has much less bulk than the ingredients apart. So also of a pound of sugar dissolved in a pound of water.

78. Water, and liquids generally, resist compression very powerfully. It was long believed that water was absolutely incompressible; but it is found that at 1,000 fathoms down in the sea the water is compressed by the superincumbent water so as to have bulk about a hundredth part less than at the surface.

79. In aeriform masses the atoms are very distant, and hence the masses are more easily compressed. A pint of water on assuming the aeriform state, in which it is called steam, under ordinary pressure, acquires nearly 2,000 times its former bulk. Fifty pints of common air may be compressed into a pint vessel, as in the chamber of an air-gun. Of some gases if the pressure be much farther increased, the particles at last collapse and form a liquid.

The comparative *weights* of *equal bulks* of different bodies are called their *specific gravities*.

80. In thus comparing bodies, it was necessary to choose a standard of comparison; and water, as being the substance most easily procurable at all times and in all places, has been generally adopted.

The metal called platinum, the heaviest of known substances, is about twenty-two times as heavy as an equal bulk of water, and is therefore said to have specific gravity of 22—gold is nineteen times as heavy as water—mercury thirteen and a half —lead eleven—iron eight and a half—copper eight—common stones about two and a half—woods from a half to one and a half—cork one quarter, &c.

81. "*Hardness*" is not proportioned, as might be expected, to the density of the different bodies, but to the strength of the polarity of the atoms in them, that is, to the force with which the atoms hold their places in some particular arrangement.

Hardness is measured generally by the circumstance of one body being capable of scratching another. It is worthy of notice, however, that the powder or dust of a softer body, if moved rapidly against a harder in a way to be described below, will aid in wearing down or polishing the harder.

Gold, though soft, is four times heavier than the hard diamond; and mercury, which is fluid, is nearly twice as dense as the hardest steel.

82. Diamond is the hardest of known substances. It cuts or scratches every other body, and is generally polished by means of its own dust.

Glaziers use a point of diamond as a glass-knife for dividing and shaping their panes.

Common flint also cuts glass, as is proved by the scribblings on windows.

83. It is remarkable, that the preparation of iron called steel, may either be soft like pure iron, or, by being heated and suddenly cooled, in the process called tempering, may become nearly as hard as diamond. The discovery of this fact is perhaps second in importance to few discoveries which man has made; for it has given him all the edge-tools and cutting instruments by which he now moulds every other substance to his wishes. A savage would work for many months, with fire and sharpened flints, to fell a great tree, and to give it the shape of a rough canoe; where a modern carpenter, with his tools of steel, could accomplish the object better in a few days.

The project has lately been realized of making engravings of pictures on plates of soft steel instead of on copper, and afterwards tempering the steel to such hardness, that it can be used as a type or die to make its impression, not only on paper, but on other plates of soft steel, or of copper, each of which is then rendered valuable like an original and distinct engraving. By this means beautiful productions of the pencil, instead of being limited to a comparatively small number of copies at high prices, may be multiplied almost to infinity, becoming the cheap delight of many.

84. "*Elasticity*" is present in a mass when the particles, cohering strongly in a particular arrangement only, yield, however, to a certain extent, when force is applied, but move back or regain their former positions on the force being withdrawn.

Elastic bodies vary much as to the extent to which they yield without breaking, and as to the degree of perfection with which, after the bending, or displacement of atoms, they regain their former state. India rubber is extensively elastic, for it yields far; but it is not perfectly elastic, for when stretched much or

often, it becomes permanently elongated. Glass, again, is perfectly elastic, for it will retain no permanent bend; but, unless in very thin plates indeed, or in fine threads, it will not bend far without breaking.

All hard bodies are elastic, as steel, glass, ivory, &c., and many soft ones, as caoutchouc, silk, a harp string, &c. The aeriform bodies are all perfectly elastic, as is at once seen in a bag or cushion filled with air, when squeezed in any way and in any degree, and allowed to expand again; and they will change volume to a very great extent. Liquids also are perfectly elastic, but to a small extent.

A steel sword, or other long plate of good steel, may be bent until its ends meet, and yet when allowed will return to perfect straightness. But a rod of inferior steel, or of other metal, will break in bending, or will retain a bend.

85. An ivory ball, let fall on a marble slab, rebounds instantly, owing to the great elasticity of both bodies, nearly to the height from which it fell, and no mark is left on either. If the surface of the slab be wet, it is seen that the substance of the ivory or marble, or of both, had yielded considerably near the point of contact, for a circular surface of some extent on the slab is found to be dried by the blow. The sudden expulsion of air from between the meeting surfaces might contribute to the effect, but the result is very nearly the same when the experiment is made in a vacuum. Billiard-balls scarcely lose even their polish by long wear, although the touching parts yield at every stroke.

A marble chimney-piece long supported by its ends, is found at last to be somewhat bent downwards in the middle; and the bend is permanent.

A steel watch-spring, although so much and so constantly bent, resumes its original form when set free at the end of a century; but occasionally, without evident cause, while in action, it will suddenly give way.

Elasticity is a property in bodies of great utility to man, as in his time-pieces, carriage-springs, gun-locks, &c. &c.

"*Brittleness*" designates that constitution of a body where, with hardness, and elasticity perfect as far as it goes, the cohesion among the atoms exists within such narrow limits that a very slight change of position or increase of distance among them is sufficient to

produce a rupture. A comparatively slight force, therefore, if sudden, breaks them. Brittleness belongs to most very hard bodies.

Glass scratches pure iron, proving that it is harder than iron —yet glass is the very type of fragility; yielding to the stroke of soft wood, or indeed of almost anything which can give a blow.

Steel, when tempered so as to be very hard, becomes brittle also. The steel chisels and tools with which artificers can now shape stones and metals, as they formerly did wood, require of course to be exceedingly hard; but they thereby lose in regard to the *extent* of their elasticity, and hence are frequently broken. Cast iron, which is much harder than malleable or wrought iron, is very brittle, while soft iron and steel are the toughest things in nature.

"*Malleable*," or reducible into thin plates or leaves by hammering. This property, in opposition to elasticity and brittleness, belongs to bodies whose atoms cohere equally in whatever relative positions they happen to be, and therefore yield to force, and shift about among each other, without fracture or change of property, almost like the atoms of a fluid.

86. Gold is remarkably malleable, for it may be reduced to leaves of such thinness, that 1,800 put together only equal in thickness a sheet of common paper. For gold-beaters the metal is first formed into rods; these are afterwards rolled or flattened into ribands; the riband is then cut into strips, which are farther extended by hammering to great breadth and thinness, and these being again subdivided, are ultimately hammered out to the thinness described.

Silver, copper, and tin may similarly be hammered until rendered very thin. Most other metals crack or are torn before the operation is carried far; and some, on being first struck, are broken at once, almost like glass.

87. Iron, when heated to redness, becomes singularly soft and malleable. Under the forge-hammer, or other mode of compression, it takes useful forms as readily almost as potter's clay. Between rollers it can be spread into sheets as thin as paper, or elongated into the uniform solid bars for railways. Many other metals and their alloys, under the blow of the coining press take

from engraved dies of hard steel delicate impressions as sealing-wax does from cut stones.

"*Ductile*," or susceptible of being *drawn* into wire.

It might be expected that malleability and ductility would belong to the same substances and in the same degrees—but it is not so. In ductile substances, as in malleable, the atoms seem not to have more fixed relations of position than in a liquid, yet they cohere very strongly.

88. To form wire, one end of a rod of iron, or other ductile metal, being reduced in size so as to pass through an opening in a plate of hard steel, is seized beyond the plate by strong nippers, and the whole rod is drawn through. It is thus reduced, of course, to the size of the opening, and is lengthened in a like proportion. By repeating the operation through smaller holes in succession, a wire may at last be obtained of the size of a hair.

Dr. Wollaston's ingenuity produced platinum wire finer than spider's thread. He filled the hollowed axis of a silver wire with a platinum wire. He then drew or reduced the compound length to the smallest size attainable, and on dissolving the silver from the outside, there was left the delicate filament of platinum.

The order in which metals may be arranged according to their ductility is—platinum, silver, iron, copper, gold, &c.

89. Melted glass has great ductility. The workers draw or spin it into fine threads, by merely attaching a point pulled out from the mass, to the circumference of a turning-wheel. A uniform thread then continues to be drawn out and wound upon the wheel, at the rate of many yards per minute. This glass thread, when laid together in quantities, resembles beautiful hair.

"*Pliant*." In substances distinguished by this title, the cohesion of the particles is not destroyed by sharp or sudden bending of the fibres. Threads of them can be knotted or woven into cloth. Unlike what happens in a ductile mass, the same atoms never change their contact.

Of pliant things the chief are animal and vegetable fibres and membranes—as silk, bladder, lint, hemp, skin, &c.

90. "*Tenacity*" means the force of cohesion among the particles of any mass. It belongs in some degree to all solids, and even to liquids.

This property varies much in different substances. Iron and its modification called steel possess it in the most remarkable degree.

The following table shows the comparative tenacity, or strength to resist pulling, of certain metals and woods. Supposing similar wires or rods of each to be used, and of such size that the surface of a broken end or cross-section would be the one-thousandth of a square inch, the weights supported would be nearly as follows:

METALS.	
Cast Steel	134 lbs.
Best wrought Iron	70
Cast Iron	19
Copper	19
Platinum	16
Silver	11
Gold	9
Tin	5
Lead	2
WOODS.	
Teak	13 lbs.
Oak	12
Beech	$12\frac{1}{2}$
Ash	14
Deal	11

Iron, compared in this way with oak, is five or six times stronger than it.

Steel wire will support the weight of about 39,000 feet (or $7\frac{1}{2}$ miles) of its own length.

Certain animal substances have great tenacity: as—the silkworm's thread, which is our strongest connecting or sewing material, and has perfect flexibility united with its strength—the ligaments and tendons of the animal body, possessing at once admirable strength, elasticity, and pliancy: these, when dried, and otherwise prepared, constituted the tough bow-strings of our remote forefathers—the hair or wool of animals, twisted into threads, and worked into the strong and beautiful textures of the loom—strips of animal intestine, prepared and twisted, forming the cords of harp and violin, and in strength and uniformity rivalling the steel wires of keyed instruments.

91. The gradual discovery of substances possessed of strong

tenacity, and which man can yet easily mould to his purposes, has been of great importance to his progress from low to higher civilization. The place of the hempen cordage of European navies is still held in some tropical countries by twisted canes and strips of bamboo; and even the hempen cable of Europe, so great an improvement on former usage, has now given way to the more complete and less bulky security of the iron chain—of which the material to our remote ancestors existed only as a useless stone or earth. And what a magnificent spectacle is it, at the present day, to behold chains or other forms of tough iron stretched high across a channel of the ocean, as at the Menai Strait, between England and Anglesey, and supporting there an admirable bridge-road of safety, along which crowds, and even railway trains, may at all times pass, regardless of the deep below, or of the storm ; while under it great ships with sails full spread may pursue their course, unmolesting and unmolested!

SECTION II.—THE MOTIONS OR PHENOMENA OF THE UNIVERSE.*

ANALYSIS OF THE SECTION.

The bodies or masses composing the universe may be at rest or in motion, and to change any present state, force proportioned to the quantity of the body and to the degree of change, is equally required, whether to give motion, to take it away, or to bend it :—a truth expressed by saying that matter has INERTIA, *or figuratively, a stubbornness. Uniform straight motion, then, is as naturally permanent as rest. And the motion in any body, estimated by its velocity, quantity of matter, and direction, is the measure of the amount and direction of any single force, or of the result of any combination of forces, which has produced it, as also of the force or momentum which the body can exhibit again when opposed or made to act itself as a cause of some new motion.*

The great forces of nature, referred to by the two words ATTRACTION *and* REPULSION, *acting upon* INERT matter, *produce the* equable, accelerated, retarded *and* bent *motions which constitute the great phenomena of the universe.—Tides, currents, winds, falling bodies, &c. exemplify* attraction.—*Explosion, steam, collision, &c., exemplify* repulsion. *And as in every case of attraction or repulsion, two masses at least must be concerned, there is no motion or* action *in the universe, without an equal and opposite motion or* re-action.

"Motion and Force."

92. Motion is the term applied to the phenomenon of the changing of place among bodies; and Force designates whatever gives, takes away, or changes motion.

Were there no motion in the universe it would be dead. It would be without the rising or setting sun, or river-flow, or moving winds, or sound, or light, or animal existence.

To understand then the nature and laws of the motions or changes going on around him, is to man of prime importance, as it enables him to adapt his actions to what is coming in futurity, and often to interfere so as to control futurity, for his special purposes.

93. Motion in any particular case is described by referring to certain known objects around, to mark place and direction, and to some other known motion chosen as a standard of speed.

* The reader should here read again the summary at page 1.

A man sitting on the deck of a sailing ship, has *common* motion with the ship: if walking on the deck, he has *relative* motion to the ship: but if he be walking towards the stern, just as fast as the ship advances, he is at rest relatively to the bottom or shore. A ship sailing against the tide, just as fast as the tide runs, is as much at rest relatively both to the earth and water, as if she were at anchor. *Absolute* motion is that which is relative to the whole universe, or rather to the space in which the universe exists. We have as yet no certain means of ascertaining this.

94. Motion may be *rapid*, as that of lightning—*slow*, as that of the sun-dial shadow: both terms having reference to the ordinary intermediate velocities observed upon earth. It is called *straight*, or *rectilineal*, in the apparent path of a falling body—*bent*, or *curvilinear*, in the track of a body thrown obliquely—it is *uniform* or describing equal spaces in equal times, in the hands of a clock—*accelerated*, in a stone falling to the earth—*retarded*, in the stone thrown upwards while rising to the point where it stops before again descending.

Examples of different common velocities are—

Man walking . .	from 3 to 4	miles in the hour.
Horse trotting . . .	7	ditto
Horse galloping .	from 40 to 60	ditto
Railway train . .	„ 25 to 50	ditto
River current . .	„ 3 to 4	ditto
Gentle wind	7	ditto
Hurricane	90	ditto
Sound	1140	feet in a second.
Rifle ball . . .	1400	ditto
Electricity . . .	50,000	miles in a second.

"*Owing to the* INERTIA *of bodies force is equally required to impart motion and to take it away.*" (Read again the last analysis.)

95. If a man put his hand to the crank of a heavy fly-wheel or grindstone, to turn it, he experiences a certain resistance, which however gradually yields to his effort, and he leaves the wheel going round with velocity proportioned to the effort made. If he then put out his hand again to stop the wheel, he experiences a similar but opposite resistance, which, however, as before, gradually yields, and he brings the wheel to rest. In the second case the effort required of him is less than in the

first, because the friction of the turning axle, and the resistance of the air in which the wheel moves, were obstructions when he was giving motion, but aids when he was taking it away. That these obstructions cause the whole difference in such a case, and that they are the great reasons why all ordinary motions on earth seem to tend of themselves to cease, will be shown in subsequent pages. It is the resistance overcome in first moving the wheel or in afterwards stopping it, and occasioning in both cases an expenditure of force proportional to the mass and to the degree of change produced, which is called the INERTIA of the mass, or the *vis inertiæ*, and sometimes, to help the conception of the student, the *stubbornness* or *persistence* of the mass; but no one of these terms without illustrative facts adduced can suggest to the student all that is intended to be conveyed.

96. A simple measure of the amount of inertia is contained in the familiar fact, that any body set free near the surface of the earth, falls nearly 16 feet in the first second of time,—the well-known weight of the body, or force of terrestrial attraction acting upon it for one second, being just sufficient to overcome its inertia to the extent stated. Were the inertia of matter only half of what it is, a body near the earth would fall 32 feet in a second, instead of 16, as it equally would, if, with present inertia, the attraction of the earth were doubled. And were there no inertia, a body would fall or pass through any space, however great, in one instant. As the amount of inertia thus determines the amount of the force required to give a certain motion to a mass, so does it determine the amount of force required to destroy motion in a mass. A heavy cannon-ball, if wanting inertia, might be despatched with the speed of lightning by the slightest force, but then the stiffness of a stalk of corn would suffice to arrest it; and while the ball, with the force of inertia now existing, takes the force of pounds of gunpowder to give it a usual speed, it may not be stopped, even by the cohesion of a block of granite, which accordingly it shivers to pieces. The numerous examples now to follow will prove the all-pervading influence of *inertia* in the general phenomena of nature.

97. When the sails of a ship are first spread to receive the force or impulse of the wind, the vessel does not acquire the full speed at once, but slowly, as the continuing force gradually overcomes the inertia of the mass. When the sails are afterwards taken in, the vessel does not lose the acquired motion at

once, but slowly again, as the continued resisting force of the water destroys it.

97. When a railway train starts from a station, although the full force of the steam acts instantly when the valve is opened, the desired speed of 30 or 50 miles an hour comes but gradually, and after a considerable interval. When again, near the journey's end, the steam is shut off, the train comes slowly to rest.

Horses must make a greater effort at first to put a carriage into motion than to maintain the motion afterwards: and a strong effort is required to stop a moving carriage. When a carriage is suddenly moved, a person within seems to be at the moment forced against the back cushion. When the carriage is stopped again a contrary effect is perceived.

98. A man standing carelessly at the stern of a boat, if the boat moves forward, falls into the water behind; because his feet are pulled forward, while the inertia of his body keeps it where it was, and therefore behind its support. The sudden stopping of a boat, again, illustrates the opposite inertia of motion, by the man's falling forward.

A like accident frequently happens to a passenger who, while paying the fare, remains imprudently standing on the hind step of the public carriage called an omnibus.

An awkward rider may be left behind, when his horse starts forward suddenly; or may be thrown off on one side by the horse starting to the other. A horse at speed, stopping suddenly, may send his cavalier over his ears.

A young man, not yet a skilful driver, ran his phaeton violently against a heavy coach on the road. He afterwards in a court of law foolishly blamed the injured coachman as the furious driver. At the trial, the youth and his servant both deposed, that the shock of the coach was so great as to throw them over their horses' heads, and thus lost the cause, by unconsciously proving, that the faulty velocity was their own.

99. A man jumping from a carriage at speed is in great danger of falling forward, when his feet reach the ground; for his body has as much forward velocity as if he had been running with the speed of the carriage; and unless he move his feet for a time like a running man, to support his advancing body, he must as certainly be thrown to the ground, as any runner whose feet are suddenly arrested. A man racing who receives a signal to stop, and a man jumping from a flying

vehicle, must check their motion in the same way.—On the first introduction of railways with high velocity many accidents occurred to persons who did not understand this.

A person wishing to leap over a broad ditch or chasm, first makes a run, that the motion thereby acquired may help him over—a running leap reaching much farther than a standing one.

100. In September, 1846, the noblest steam-ship which had then been built, the "Great Britain," started from Liverpool on her second voyage to New York, carrying a rich cargo and a crowd of joyful passengers, greater than had ever before sailed in one vessel. Her speed so far surpassed expectation, that one lighthouse was mistaken for another, and in the darkness of the night she was allowed at full speed to run directly on shore on the sloping sandy beach of Dundrum Bay, in Ireland. Her momentum was so great as to force her, like a ball rolled up a hill, so far up on the beach as to leave her safe from the waves even of a storm; and, strange to say, her structure was found to be so little damaged by the occurrence, that the eminent engineers Brunel and Brebner succeeded again the year following in launching her a second time to pursue her voyages, as she still continues to do.

A flying hare pursued by the still swifter greyhound, when its enemy is close upon it, often saves itself, at least for a time, by what is called "doubling," that is to say, it makes a sudden bend from the line of its flight; while the hound, not prepared for the trick, and at his greatest speed, cannot stop and turn so quickly and sharply, and when at last he has come round in his larger curve, he finds the hare already far away in a new direction.

There is a story that a traveller in Africa saw himself followed by a tiger, from which he could not hope to escape by running; but he artfully led it to where the ground terminated in a precipice hidden by brushwood, and he had just time to transfer his cap and coat to a bush, and to retreat a few paces, when the tiger sprang upon the bush, and by the motal inertia of its body was carried over the precipice, and killed.

From a glass of water suddenly pushed forward on a table, water is spilt or left behind; but if the glass be already in motion, as when carried by a person walking, and if it be then arrested by coming against any fixed obstacle, the water is thrown or spilt forward.

A servant carrying a tray of glasses or china in the dark, and

coming against an unexpected impediment, hears all the freight slipping forward and crashing at his feet; a too hurried departure with such a load would cause equal destruction, on the opposite side.

The actions of beating a coat or carpet with a cane, to expel the dust; of shaking the snow from one's shoes, by kicking against the door-post; of cleaning a dusty book by knocking it against another, or shutting it violently—all illustrate the same principle.

101. If a guinea be laid on a card which was already balanced on the point of the finger, a smart fillip or blow against the edge of the card will cause it to dart off, while the guinea, owing to its inertia, will remain resting on the finger,—its inertia being greater than the friction on it of the card passing so quickly from underneath it.

A package containing any fragile wares, as glass or eggs, if very suddenly either put in motion or stopped, as in falling from a very moderate height, causes breakage of what may be within.

A weight suspended by a spring on ship-board is seen vibrating up and down as the ship pitches with the waves. It seems to fall as the ship rises, and to rise as the ship falls: but often the motion is really in the ship, and the comparative rest is in the weight. A heavy weight so supported, and connected with a pump-rod, has been caused to work the pump.

102. Like the weight last mentioned, the mercury of a common barometer on ship-board appears to be constantly rising and falling in the tube as the ship pitches; and until the important improvement was made, of narrowing a part of the tube to prevent this, the mercurial barometer was useless at sea. The explanation is, that the tube rises and falls with the ship, from being affixed to it; but the mercury, which plays freely in the tube, and is supported by the atmospheric pressure, as explained under *Pneumatics*, tends, by its inertia, to remain at rest, and thus makes the motion of the ship apparent.

What happens to the mercury in the barometer tube on ship-board, indicates what happens to the blood in the vessels of animals under similar circumstances. In any long vein below the heart, when the body falls, the blood, owing to its inertia and the supporting action of the vessels, does not fall quite so fast, and therefore really rises in the vein: and as there are valves in the veins preventing return, the circulation is thus

quickened without any muscular exhaustion on the part of the individual. This helps to explain the effect of the movement of carriages, of vessels at sea, of swings, &c., and of passive exercise generally, on the circulation, and leaves it less a mystery why these means are often so useful in certain states of weak health.

A mass of any kind balanced by springs or otherwise within a frame can, by its inertia tending to maintain rest, be caused to mark with a pencil on paper placed near it all quick motions of the frame. Thus the motions of the ground in earthquakes can be clearly pictured and recorded, or the severe jolts of railway carriages, indicating defects in the road needing repair.

103. If a cannon ball were to break to pieces in its flight, its parts would still advance with the previous velocity. And thus, in the deadly contrivance of the Shrapnell-shell, which is a case containing a mass of musket bullets, when these are scattered at the desired distance from the devoted body of men, they retain the forward velocity of the shell, and spread death around like the near discharge of a whole battalion of musquetry.

104. On the awful occasion of a ship in rapid motion being suddenly stopped by a sunken rock, all things on board, men, guns, and furniture, start from their places and dash forwards; while the onward inertia or motal obstinacy of the hinder parts of the ship crushes the bow against the rock.

A catastrophe surpassing in violence even this occurs when two railway trains moving in opposite directions meet in collision, and their encountering velocities are united. Hence the danger of crossings of railways, and of having only single lines of rail.

106. "*Motion as naturally permanent as rest.*"

From the instances above given, it is seen that a body at rest never moves if force be not applied, and that a body put into motion retains motion, at least for a time, after the impelling force has ceased; but there is a feeling, from common experience, that motion is an unnatural or forced state of bodies, and that all moving things, if left to themselves, would gradually come to rest. It is recollected that a stone thrown forward quickly comes to rest, or a wheel left moving, or a bowl rolled on the green, or the waves of the sea after a storm—and, in a word, that there is no perpetual motion on earth.

On attentive consideration, however, it is perceived that there are great differences in the duration of such motions, and that

the differences are always exactly proportioned to evident causes of retardation, of which causes the chief are *friction* and the *resistance of the air.*

Friction is the resistance which bodies encounter when rubbing or sliding upon each other; and however much it may be diminished by art, it can in no case be entirely avoided. Air-resistance again, to motions going on in air, is of the same nature as water-resistance to motions going on in water, only less in degree: and wherever men are, there also air must be. The amount of this resistance is now perfectly ascertained.

107. Friction in various degrees is exemplified in the following facts. A ball rolled on level grass soon stops—if rolled on a carpet over a smooth floor it goes longer—if on the bare floor, it goes longer still—on a smooth sheet of ice, it hardly suffers retardation from friction, and, if the air be moving with it, will reach a distant point.

The resistance from air is thus shown. Two little windmill-wheels set in motion together with equal velocity, but of which one has the flat sides of the vanes turned to their course, and the other the edges, if moving in the air, will stop at very different times, but if placed in a vessel from which the air has been removed, they will both revolve much longer, and will stop exactly together.

As it facilitates the motion of fishes and of ships in the water, that they have tapering forms before and behind, so does it facilitate the motion of birds in the air that they have somewhat of similar form.

A large spinning top, with a fine hard point, set in rapid motion in a vacuum, on a hard smooth surface, will continue turning for hours.

A pendulum swinging in a vacuum has to overcome only the slight friction at its point of suspension, and when once in motion, will vibrate for a day or more.

108. But it is in the celestial spaces that we see motions completely freed from the two obstacles of air and friction—and there they seem eternal.

Had the human eye, unassisted, been able to descry the four beautiful moons of Jupiter, wheeling around him for these thousands of years, with such unabated regularity, and which now form, to the telescope of the astronomer, a magnificent and unerring time-piece in the sky, or had science long proved that

the velocity of our globe, in its present orbit, thousands of years ago was exactly as at the present day, the error or prejudice that motion is always tending to rest, would never have arisen. We know of nothing which is absolutely at rest. The earth is always wheeling round its axis and round the sun; the sun is moving similarly round its axis and round the centre of gravity of the solar system, and probably round some more remote centre in the wide universe, carrying all his planets and comets about his path.

109. If there were any natural tendency in moving bodies to stop, a thing floating in a trough of water, on board a sailing ship, should always be found resting against the end of the trough towards the stern; and in all the seas and lakes of the earth, the floating things should be accumulated on the western shores, because the surface of the earth is always turning to the east. We know that neither of these suppositions is truth. A man on board a moving ship can throw any body just as far towards the bow as towards the stern; although in the two cases the velocity, in regard to the earth, is very different.

Ignorance of the law of motal inertia led a story-telling sailor to assert, as a proof of the speed of his favourite ship, that when a man one day fell from the mast-head, the ship had passed forward from under him before he reached the level of the deck: the fact in such a case being, that he must have fallen on the same part of the deck, whether the ship were in motion or at rest, because his body had just the motion or rest which belonged to the ship.

Another equally sapient man, when he learned that the earth turns round once in twenty-four hours, proposed rising in a balloon and waiting aloft until the country which he desired to reach should be passing under him.

110. " *Motion naturally uniform.*" (See the Analysis.)

It is only repeating that a body neither acquires motion nor loses motion without a cause, to say that free motion must be *uniform.*

The perfect uniformity of undisturbed motion, is proved by every fact observed in the universe. If any free continued motion, as the rotation of a planet for instance, be found at one time to have a certain relative velocity to some other such motion, the same relation is found always to hold; and in other motions, deviations from perfect uniformity are always exactly

proportioned to the disturbing causes. Thus we can foretell the exact time of an eclipse, a thousand years before its occurrence.

111. Had motion not been in its nature uniform, man could have formed no rational conjecture or anticipation as to future events; for it is by assuming, for instance, that the earth will continue to turn uniformly on its axis, that he speaks of *to-morrow* and of *next week*, &c., and that he makes all his arrangements for future occupation: and were the coming day, or season, or year, to arrive sooner or later than such anticipation, it would throw such confusion into human affairs, that the world would soon be desolate.

To calculate futurities, then, or to speak of past events, is merely to take some great uniform motion as a standard with which to compare all others; and then to say of the remote event, that it coincided or will coincide with some described state of the standard motion. The most obvious and best standards are the rotation of the earth about its axis and its great revolution round the sun. The first is rendered very sensible to man by his alternately seeing and not seeing the sun, and it is called *a day;* the second is marked by the succession of the seasons, and it is called *a year.* The earth turns upon its axis nearly 365 times while it is performing one circuit round the sun, and thus divides the year into so many smaller parts called days; and the day is divided into smaller parts, by the progress of the earth's whirling being distinctly marked, in the constantly varying direction of the sun, or stars, as viewed from any given spot on the face of the earth.—When advancing civilization made it of importance for men to be able to ascertain the very instant of the earth's revolution, connected with any event, various contrivances were introduced for the purpose; as,—sun-dials, where the shadow of the stile travels progressively round the divided circle;—the uniform flux of water through a minute opening in the clepshydra;—the flux of sand in the common hour-glass, and so forth. But the great triumphs of modern ingenuity are those astronomical clocks and watches, in which the counted vibrations of a pendulum, or balance-wheel, scarcely vary by a beat in a whole year.

112. It is the natural uniformity of undisturbed motion which causes any number of bodies moving together, as the articles of furniture in the cabin of a sailing ship, to appear among themselves as if all at rest,—no one tending to pass before, or to fall

behind, or to move to one side of another. For the same reason a person who is moving with such bodies is absolutely insensible of his uniform progression, and knows it only by reasoning from such facts as the changing appearances of more distant objects around, which do not share the motion. When a ship is becalmed at sea, it may, as numberless sad accidents have proved, be carried by rapid currents in any direction, without one of the crew suspecting that it has motion at all; and if the suspicion do arise, the truth can be come at only by such means as the sounding line, where the bottom can be reached, or by careful observation of the heavenly bodies where it cannot. A man in the hold of a ship in a river or tidesway cannot say whether the rushing of water, which he hears from without, be a rapid tide passing the ship at anchor, or the effect of the ship's advance in the river. A man in a balloon going 80 miles an hour, knows not in what direction he is moving, nor indeed that he is moving at all, but by observing distant objects within his view.

113. This explains why men are not sensible of the motion of the earth itself, which they know however to be turning round its axis once in twenty-four hours, and therefore to have its surface near the equator moving with a speed of more than 1,000 miles an hour; and as in the case of a ship or balloon, there would be no difference of sensation whether the speed were of one mile per hour or of 10 or 100; so in the case of the earth, there would be none whether it turned as now, once in twenty-four hours, or, like the planet Jupiter, once in ten. A sportsman among the hills, resting during the heat of noon, and contemplating around him a sublime scene of solitude and silence, may little think that if amidst that apparent repose of nature he were for a moment lifted up from the earth and held really *at rest* above its surface, he would see its face of hill and dale sweeping past beneath him at the prodigious rate of fifteen miles in the minute, on account solely of the rotation of the earth.

114. The fact that a cannon ball can be shot just as far to the eastward, upon the surface of the earth, in the direction of the earth's motion, as to the westward, against it, illustrates the truth, that whatever *common* motion objects may have, it does not interfere with the effect of a force producing any new relative motion among them. All the motions seen on earth are really only slight differences among the great common motions: as in

a fleet of sailing ships, all bound to the same port, the apparent changes of place among them are in reality only slight alterations of speed or direction, in their nearly straight courses.

A man continuing to throw upwards a ball or orange, or several of them at once, and to catch and return them alternately, uses no difference of art as regards them, whether he be standing on the earth and whirling with it, or on a sailing ship's deck, or in a moving carriage, or on a galloping horse's back. He and the oranges have always the same forward common motion. And when a man, standing on a galloping horse, appears to leap through a hoop held across his course, he does not leap forward—for this would throw him over the horse's ears—but merely jumps up, and allows his motal inertia to carry him through.

The reason that a lofty spire or obelisk stands more securely on the surface of the earth than even a short pillar stands on the bottom of a moving waggon, is, not that the earth is more at rest than the waggon, but that its motion is uniform.—Were the present rotation of our globe to be arrested but for a moment, imperial London, with its thousand spires and towers, would, in that moment, by the motal inertia of all, be swept from its valley towards the eastern ocean, just as loose snow is swept away by a gust of wind.

"Free Motion is naturally straight, so that force is required to bend motion."

115. If a body moving freely cannot vary its velocity without a cause, neither can it vary its course without a cause; and free motion, therefore, is *straight* as well as *uniform*.

A ball allowed to fall directly down, gives men a simple idea of straight motion.

A bullet or arrow, projected horizontally in the air, is gradually drawn downwards by the attraction of the earth, but it deviates neither to the right hand nor to the left.

William Tell, trusting to the natural straightness of motion, and allowing for the effect of gravitation, obeyed the tyrant's order, and shot safely through an apple placed on his child's head.

And the right eye of Philip of Macedon is said to have been destroyed by an arrow which carried a label on it, telling its destination.

Riflemen shooting at a target, hit the very spot they choose to aim at.

116. A stone revolving in a sling, the moment it is set at liberty, darts off as straightly as an arrow from the bow-string or a bullet from a gun-barrel, and it is only because the point of its circle, from which it should depart, cannot in practice be accurately determined, that the same sure aim cannot be taken with it.

A body moving in a circle, then, or curve, is constrained, by some continuing force, to do what is contrary to its inertia. A person, on first approaching this subject, might suppose that a body, which for a time has been revolving in a circle, should naturally continue to do so when set at liberty. But as a circle in such a case may be regarded as made up of an infinite number of minute straight lines, and that the body moving in it has its motion bent at every step of the progress, the reason is seen why constant force becomes necessary to keep it there, and force just equal to the inertia with which the body tends, at every point of the circle, rather to pursue the straight line, called a tangent, of which that point, as seen in the figure, is the commencement, than the circle itself. The force required to keep the body in the bending course is called *centripetal* or centre-seeking force; while the inertia of the body tending outwards, that is, to move in a straight line rather than in a curve, is called the *centrifugal* or centre-flying force; and the term *central forces* is applied to both.

117. A sling-cord is always tight while the stone is whirling: and its tension is of course the measure, both of the centripetal and centrifugal force. A means, then, of measuring the tension of a sling-cord would experimentally demonstrate the amount of centrifugal force; and such a means we possess in the contrivance called the "whirling table." Upon this a loaded sling, or any mass with a string attached to it, may be placed to revolve, at any desired distance from the centre, and with any desired velocity, while the string passing down through the centre over a pulley, is caused to lift weights proportioned to the outward dragging of the revolving mass.

118. By this apparatus it is found, as would be expected, that centrifugal force—in other words, the force with which the inertia of moving matter resists the bending of its course from

straight to circular, is proportioned, 1st, to the quantity of matter moved—every separate particle having its own inertia; 2ndly, to the size of the circle or orbit described in a given time—a body moving round a circle of double diameter, for instance, having to be forced inwards from the tangent, at every corresponding point, twice as far in a given time; 3rdly, that with a double revolution in the same circle and in the same time, the centrifugal force is not double but quadruple (a corresponding proportion existing for other velocities), because, not only are there twice as many bendings or angular departures from the tangent for the two revolutions as for one, requiring, as may be said, twice as many tugs or impulses of the centripetal force, but every impulse must be made with double energy, for it has to drive the mass inwards through the required distance in half the time; and twice as many impulses, every one being twice as strong, make up a quadruple amount of force on the whole; 4thly and lastly, it is found, agreeing with the relation between inertia and terrestrial gravity described at page 62, that a body revolving, for instance, in a circle of four feet diameter, that it may have centrifugal force just equal to its weight, requires to complete its revolution in one second and a half of time. This and similar facts are more particularly considered in the Mathematical Appendix. This analysis of central forces will suffice to excite in the student a due interest touching the selected phenomena now to be described.

119. Loose bodies laid on any whirling horizontal wheel or table, are quickly thrown off.

In a corn-mill, the grain, after being admitted between the stones through an opening in the centre of the upper or turning stone, is then kept moving round between them, and is, by its centrifugal force, always tending and travelling outwards until it escapes as flour from the circumference.

Were a man to lie down on a quickly-turning horizontal wheel with his head near the edge, he would soon fall asleep, or might die of apoplexy from the new pressure of blood on the brain.

120. If the rotation of a heavy wheel or grindstone be made very rapid, the material near the circumference tends outwards so strongly by its centrifugal force that it may be torn away or ruptured with extreme violence. This has happened to grindstones at Birmingham, and to wheels of railway-car-

riages, the fragments then passing through the carriage almost like cannon balls.

121. A wet mop, or bottle-brush trundled or made to turn quickly on its handle as an axis, throws the water off on all sides, and soon dries itself.

122. Sheep, in wet weather, thus discharge the water from their fleeces, by a rapid semi-rotatory shake of the skin. Water-dogs, on coming to land, dry themselves by a similar action.

123. Lately the important business of washing linen has been much simplified by transferring the wet linen directly from the wash-tub to a cylindrical case pierced all round with holes, and which is then caused to whirl with extreme rapidity. The centrifugal force of the water causes it to escape all round, and in two or three minutes the linen is taken out nearly dry.

124. A tumbler of water, placed in a sling, may be made to vibrate, first, like a pendulum with gradually widening oscillation, and soon to go round the whole circle like a stone in a sling, continuing to revolve about the hand, without spilling a drop:—the water, by its inertia of straightness, or centrifugal force, then tends more away from the hand or centre of motion towards the bottom of the tumbler, even when that is uppermost, than towards the earth by its weight.

125. As solid bodies laid on a whirling table are thrown off to the circumference, so water in a vessel caused to spin round in any way, as when placed on the centre of a horizontal wheel, instead of remaining at rest on the bottom, is raised up all round, against the sides of the vessel.

Water, poured obliquely into a funnel, runs round the interior of it, and may even leave an open passage all the way through it, as if it were merely a lining to the funnel.

126. Whirlpools and eddies in water occur whenever a current is caused suddenly to bend, as in rounding a point of land or a sunken rock, or in meeting and mingling with a contrary current. The water, by tending to continue its straight motion, falls in, reluctantly as it were, behind the obstruction, and leaves there a depression of the surface surrounded by a liquid revolving ridge. Kindred occurrences take place in the ocean of air above the earth, causing the phenomena of whirlwinds, hurricanes, &c.

127. It is owing to the centrifugal force in any bending part of a stream of water, that is to say, to the tendency away from the centre of the curvature, that when a bend has once com-

menced from any cause, it increases and is soon followed by others, until that complete serpentine winding is produced, which characterizes most rivers in their course across extended plains. The water being thrown by any cause to the left side, for instance, wears that into a curve or elbow, and by its centrifugal force, acts constantly on the outside of the bend, until rock or higher land resist the gradual progress; the stream being then thrown back again, wears a similar bend to the right hand, and after that another to the left, and so on.

128. Carriages are often overturned in quickly rounding corners. The inertia urges the body of the vehicle onwards in the former direction, while the wheels are suddenly pulled round by the horses into a new one. Thus a loaded stage-coach running south, and turned suddenly to the east or west, may strew its passengers on the south side of the road. Where a sharp turning in a carriage-road is unavoidable, the road towards the outside of the bend should be made higher than on the inside, to prevent such accidents.

129. A man or a horse turning a corner at speed, leans much inwards or towards the corner, to counteract the centrifugal force, that would throw him away from it.

130. In skating with great velocity, this leaning inwards at the turnings becomes very remarkable, and gives occasion to the fine variety of attitudes displayed by the expert. If a skater, in running, finds his body inclining too much to one side, and threatening to fall, he merely turns his skate slightly towards that side, and the tendency of his body to move straightly, refusing to follow in the curve, allows the foot to regain its place under the body, and to restore the perpendicularity. Skating becomes to the intelligent man an intellectual, as well as a sensitive or bodily treat, from its exemplifying so pleasingly the laws of motion.

131. The last example explains, also, why a hoop rolled along the ground goes so long without falling: if it incline to one side, threatening to fall, by that very circumstance the part touching the ground bends its course to that side, and as in the case of the skater who turns his foot, the supporting base is again brought directly under the body.

A coin dropped on the table or floor, often acquires a degree of rotatory motion and then exhibits the same phenomenon. It is said to run and hide itself in the corner. Just before falling, if not obstructed, it describes several turns of a decreasing spiral.

132. One of the reasons why a spinning top stands, will be understood here. While the top is quite upright, the extremity of its peg, being directly under its centre, supports it steadily, and although turning so rapidly, and with much friction, has no tendency to move from the place; but if the top incline, the *edge* or *side* of the peg, instead of its very *point*, is in contact with the floor, and the peg then becoming as a turning little roller, advances quickly, and describes a curve somewhat as a skater's foot does, until it come directly under the body of the top as before.

133. By reason of centrifugal force also, it is easier to do feats of horsemanship while moving in a ring, as at our theatres, than if the animal were running on a straight road. We see the man and horse always inclining inwards, to counteract centrifugal force; and if the rider tend to fall inwards, he has merely to quicken the pace a little, if to fall outwards, he has to slacken it, and all is right again.

134. If a pair of common fire-tongs, suspended by a cord attached to the top, be made to turn by the twisting or untwisting of the cord, the legs will open out or separate from each other with force dependent on the speed of rotation, and will again collapse when the turning ceases. Mr. Watt adapted this fact most ingeniously to the regulation of the speed of his steam-engine. His *steam-governor* may in truth be described as a pair of tongs or rods jointed at their top with heavy balls at the lower ends, to make their opening more energetic, connected with some turning part of the engine. If the engine move with more than the desired speed, the balls open out or fly asunder, and by so doing are caused to narrow the steam-valve; on the contrary, with too slow a motion, they collapse and open the valve wider.

135. A half-formed cylindrical vessel of soft clay, placed on the centre of the potter's table,—which is made to whirl, and is called his wheel,—opens out or widens merely by the centrifugal force of its sides, and thus assists the worker in giving its form.

136. A ball of soft clay, with a spindle fixed through its centre, if made to turn quickly, soon ceases to be a perfect ball. It bulges out in the middle, where the centrifugal force is greatest and is flattened towards the ends, where the spindle issues.

137. This change of form is exactly what has happened to the ball of our earth. It has bulged out thirteen miles and a fraction

at the equator, in consequence of its diurnal rotation, and is flattened at the poles in a corresponding degree.—A mass of lead that weighs 287 pounds near our pole, weighs just one pound less at the equator, owing conjointly to the centrifugal force, and the greater distance from the centre produced by the bulge.

In the planets Jupiter and Saturn, of which the rotation is much quicker than of our earth, the middle or equator bulges out still more—even so as to offend an eye which expects to see a perfect sphere.

138. If the rotation of our earth were seventeen times faster than it is, the bodies or matter at the equator would have centrifugal force nearly equal to their gravity, and a little more velocity would cause them to fly off altogether, or to rise and form a ring round the earth like that which surrounds Saturn. Saturn's complex ring is supported chiefly by the centrifugal force of the parts. Were it to crumble to pieces, the pieces might still revolve, as so many little satellites. His true satellites are only more distant masses sustained in the same manner. And our earth and the other primary planets have the same relation to the sun that these satellites have to Saturn—all being sustained by an admirable balance between centrifugal force and gravity.

"*The quantity of motion in a body measured by the velocity and quantity of matter.*" (Read the Appendix.)

139. If a single atom of matter were moving at the rate of one foot per second, it would have a definite quantity of motion expressed by these words; and if it were moving ten feet per second it would have ten times the quantity. Again, in a mass consisting of many atoms, the quantity of motion would be just as much greater, as there were more atoms in it than one.

140. By experiment it is found, that if a ball of soft clay of one pound, suspended by a cord as a pendulum, be allowed to fall, with a velocity of ten feet per second, against a ball of nine pounds suspended in the same way, but at rest, the two, after contact, will start together at the rate of one foot per second, the original quantity of motion being then diffused through ten times the quantity of matter, and therefore exhibiting only one-tenth of the velocity.

141. A cannon-ball of a thousand ounces, moving one foot per

second, has, thus estimated, the same quantity of motion in it as a musket-ball of one ounce, leaving the gun-barrel with a velocity of a thousand feet in the second.

"*The quantity of motion in a body is the measure of the force which produced it.*"

142. The experiment of the balls of clay mentioned above furnishes one instance of this truth. Again, a body falling for ten seconds, acquires ten times as much velocity as by falling for one second; its speed thus measuring the force of gravity which has acted upon it.

When a large body or mass of many atoms falls, it of course has as much more motion than a smaller body, as there are more atoms in it than in the smaller: but as gravity must act equally on every atom, the force causing either body to fall is still exactly indicated by the quantity of motion in it.

A large body or a mass of many atoms falls, where there is no impediment, with the same velocity as a smaller body or a single atom; for gravity has to pull equally at each atom to overcome its inertia, whether it be alone or with others.

143. This remark contradicts the popular opinion, that a large and heavy body should fall to the earth much faster than a small and light one; an opinion which has arisen from our constantly seeing such contrasts, as the rapid fall of a piece of gold and the slow descent of a feather. The true cause of the contrast is, that the atoms of the feather are much spread out, so as to be more resisted by the surrounding air than those of the gold. If the two be let fall together in a vessel from which the air has been extracted—as in the common air-pump experiment,—they arrive at the bottom in exactly the same time: and even in the air, if the gold be hammered out into gold leaf, it will fall still more slowly than the feather. One brick dropped from a height, because its motion is not much affected by the air, reaches the earth very nearly as soon as ten bricks let fall near it, whether they be connected or separate—as a single horse can reach the goal as soon as ten horses galloping abreast.

A man's force will move a small skiff quickly, a loaded barge very slowly, and a large ship in a degree scarcely to be perceived. In each case, however, the quantity of motion may be the same, and a true measure of the force which produced it.

144. "*The quantity of motion in a body is the measure also of the force or momentum which it can exhibit again.*" (See the Analysis, page 35.)

Bodies, owing to their inertia, may be regarded as passive reservoirs of force or motion, always ready to receive more or to return what they have received. *Momentum* is the name given to the motion in a body, with reference to the production by it of new motions or the overcoming of resistances, and is but another term for the *quantity of motion.*

A cannon-ball, according to the quantity of motion in it, may have only the force or momentum that will bruise a plank, or it may have enough to penetrate a tree, or even to shoot its rapid way through a block of hard stone.

A block of wood, floating against a man's leg with moderate velocity, would be little felt; but a loaded barge, coming at the same rate, and pressing it against the quay, might break the bones; a large ship, although moving no faster, would crush his body against any fixed obstacle; and a great iceberg, opposed in its approach to another, even by a first-rate man of war, might destroy that, as meeting barges destroy a floating egg-shell.

A hail-stone falling, strikes sharply; a piece of rock rolled from a height, as of old, by the besieged against besiegers, may carry death with it to many; an avalanche, breaking from its hold on a mountain steep, may sweep away a village.

145. To meeting bodies, the shock is nearly the same, whether the motion be shared between them or be all in one.

If a running man come against a man who is standing, both receive a certain shock. If both be running at the same rate in opposite directions, the shock is doubled. In some such cases, as where swift skaters meet, the shock may prove fatal.

The meeting fists of boxers not unfrequently dislocate or break bones.

A man's skull is fractured as certainly by its being dashed against a tree or beam, while he is on a galloping horse, as by the blow of such a beam falling upon him with the velocity of the horse.

146. When two ships in opposite courses meet at sea, although each may be sailing at a moderate rate, the destruction may be as complete to both as if each with a double velocity had struck on a rock. Many instances of this kind are on record. In the

darkness of night a large ship has met one smaller and weaker, and, all within a few seconds, have occurred the shock of the encounter, the scream of the surprised victims in the weaker ship, and the awful silence when the waves had again closed over them and their vessel for ever.—In November 1825, on the coast of Scotland, the Comet steam-boat was thus destroyed, and carried to the bottom with her about seventy passengers, into whose ears the drowning water was rushing when the sounds of arrested music and joy had scarcely died away.

" Direction of the force or forces producing motion."

147. The directions from any one point are as numerous as the rays of light which can issue from a taper. A ship sailing from Dover in one direction reaches the Atlantic, in others, the coasts of Spain, France, Holland, the Baltic, &c.

When only one force acts on a body, the body obeys in the exact direction of the force.

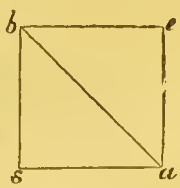
A ball floating in water, or lying on smooth ice, is driven directly south by a wind blowing to the south. A bullet issues from the mouth of a cannon, in the direction of the bore or axis of the cannon—which is, as the force impels it.

148. When two or more forces, not in the same direction, act upon a body at the same time, as it cannot move two ways at once, it holds an intermediate course between the directions. This course is called the *resultant direction,* viz. resulting from the *composition of the forces.*

149. A boat or ship driven south by a direct wind, may, at the same time, be carried east, just as fast, by a tide or river current moving east: every instant, therefore, it will go a little *south* and a little *east,* and really will describe a middle straight line pointing *south-east.*

150. These particulars can be well represented on paper, as by fig. 1: where b is the original place of the boat or ship, s the south with the length of line, $b\,s$ marking the strength of the wind, e is the east with the length of line, $b\,e$ (here equal to $b\,s$) marking the strength of the current. When the figure is completed by drawing the line $e\,a$ parallel to $b\,s$ and the line $s\,a$ parallel to $b\,e$ (which lines meet in the point a), it is called the parallelogram

Fig. 1.



of forces, and is a most important help to the understanding of many facts in Natural Philosophy. (See the Appendix.)

151. When two forces act upon a body, like the wind and tide in the given example, the result is the same, whether they act together or one after the other. For instance, if the wind drive a vessel one mile south, as from *b* to *s*, fig. 1, and immediately afterwards the tide drive it one mile east, as from *s* to *a*, the vessel will be in the same place at last, viz. at *a*, as if she had been driven at once south-east, in the line *b a*, by the simultaneous action of the two. Therefore by first drawing the lines *b s* and *b e* to represent the directions and comparative forces of the two causes of motion, and by then adding one of these, or an equivalent, to the end of the other, as *s a* to *b s*, or *e a* to *b e*, the square or parallelogram is sketched, of which the middle line, or *diagonal*, as it is called, shows the *resultant* of the forces, and the true course of the body obeying them.

152. What is thus true of the effect of the union of continued forces like wind and tide, is true also of momentary impulses, like the blows of two clubs simultaneously striking a ball, or of two billiard-balls striking a third; and it is true also of the very important cases of rest produced by balancing pressures when represented by the same lines *b s* and *b e*, tending to produce motion, but exactly balanced by a third represented by *a b*, acting in the contrary direction from *a* to *b*, and maintaining rest.

153. When two forces exactly cross each other, and are equal, as in the case of the ship above supposed, the figure or parallelogram is a square, as at fig. 1; but if one of the forces be greater than the other the figure becomes oblong, as at fig. 2;

Fig. 2.

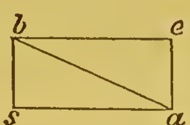


Fig. 3.

Fig. 4.

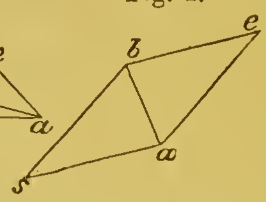
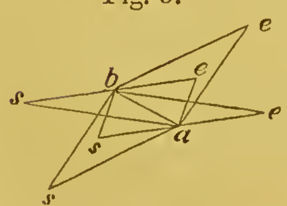


Fig. 5.



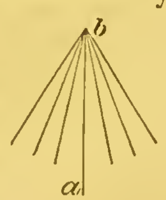
if the forces cross obliquely, the figure becomes oblique, as at fig. 3; and if they cross in an opposing direction, it will be as at fig. 4. In all the cases, however, the diagonal still shows the *result*. It is evident that the same line may be the diagonal of many figures, as seen in *b a* at fig. 5; and therefore,

that very different degrees and directions of combined forces may produce the same *result.*

154. Forces crossing each other so obliquely as to be represented by lines drawn in almost opposite directions, would form a parallelogram having scarcely any breadth, that is to say, the diagonal would approach to nothing; showing thus, that opposing forces neutralize or destroy each other. In fig. 4, by reason of this crossing, the *resultant* is less than either of the constituents. And for the same reason, when forces cross so acutely as to advance nearly parallel to each other, the *resultant* is longer than either, as seen in fig. 3. Forces directly opposed, or entirely agreeing in direction, give as their resultant their difference or their sum.

155. Forces crossing each other directly, or at right angles, as is true of the exactly eastward force *b e*, and the exactly southward force *b s*, in figures 1 and 2,—do not in the slightest degree neutralize or alter each other, for the body when arrived at *a* is just as far east as it would be at *e*, and as far south as it would be at *s*. This explains why the progressive motion of a planet in a circular orbit is not at all affected by the directly crossing centripetal force of gravity which keeps the planet at its due distance from the sun.

156. In all cases where the two crossing forces are equal, with whatever obliquity they cross, the resulting direction must be exactly midway between them.—Thus a boat impelled by oars, goes straight, although the direction in which the oars act is constantly changing; because the changing obliquity of the force is always the same on both sides.—This explains also why a bird flying, or a man swimming, holds a perfectly straight course, although in both cases the direction of the impelling forces is constantly varying.—And it explains why a body suspended, as a plummet, or falling to the earth, as an apple does from a tree, is always in a line towards the centre of the earth: for, while the part of the earth immediately under the body is pulling it straight down to the centre, the action of parts on any one side of the perpendicular is exactly counterbalanced by the action of the corresponding parts on the opposite side; and the perpendicular *b a* is still the diagonal or middle line of every pair of attracting parts. In speaking of the attraction of our earth, therefore, which really is the united attraction of all the individual atoms, we may always consider it as a single force acting towards the centre of the earth.

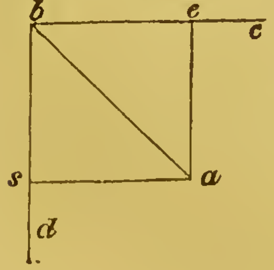


157. When a body is carried below the surface of the earth its weight becomes less, because the matter then above it is drawing it up, instead of down, as before. A descent of a few hundred feet makes a sensible difference, and at the centre of the earth, if man could reach it, he would find things to have no weight at all; and there would be neither up nor down, because bodies would be attracted equally in all directions.

158. When more than two forces act on a body, the resulting direction may be found, first of two, and then of the last *resultant* with each of the others successively—or the forces may be represented on paper by lines tacked together, of which lines one denotes the strength and direction of each force: the extremity of the last line will mark the place of the body after being acted upon by the combined forces. A sailor thus, to know the true place of his ship and the course which she has steered, considers, first, the forward progress as found by the log, then the leeway or sideward motion produced by a cross wind, and then the effect of any tide or current in which he may be sailing.

159. *Resolution of Forces* is a phrase pointing to another important use of such parallelograms or figures as have just been described, *viz.* the enabling us, when any force or motion is given, to find the forces or motions in any other directions of which it may be the *resultant*, and those into which it may itself be resolved.

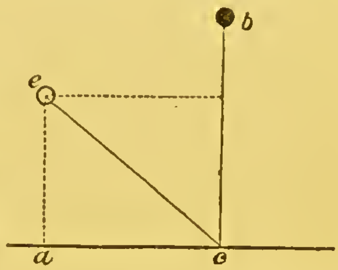
Thus, if a line *b a* (in any of the preceding figures 2, 3, 4, &c.) represent a force or motion, and the line *b s* represent one of two elements composing it, we have but to complete the parallelogram *b s a e* to obtain the other line, *b e* representing the only other single force or motion which, combined with the first element, can produce the given resultant.—If the ship pass from *b* to *a* (fig. 3) while sailing through the water eastward, a distance expressed by *b e*, she must at the same time have been carried by the tide or current to the distance and in the direction marked by the line *b s*.



160. Again, if a line be given representing a single force, or motion, as *b a*, and if it be desired to know how much there is in this capable of acting in another direction, as *b d*; it is only necessary to draw a line in the direction *b d*, from the commencement of *b a*, and to cut such line by another drawn directly upon it—or at right angles to it, as

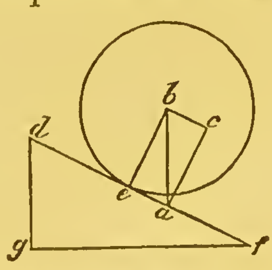
the term is, from the other end of *b a:* the length of *b d*, so cut off, *viz. b s*, shows the proportion required.

It is thus that a sailor, who knows how far he has sailed in any oblique direction, finds out how much he has gone north and east, or south and west; in other words, finds out the difference of latitude and longitude between his present place and a former one. In the above figure, *b a* may represent the course and distance sailed, *b s* the difference of latitude, and *b e* the difference of longitude.



161. Thus again, if a ball *b* strike a table, *a c*, with velocity and direction, both represented by the line *b c;* and if the ball be supposed afterwards with the same velocity to approach the table in the oblique direction *e c*, it will then strike with as much less force than before, as the line *e a* is shorter than *e c*. For *e a* is found, according to the rule for decomposing a force, given above: and, to common sense, it is obvious, that if the whole velocity of the ball be represented by *e c*, the rate of approximation towards the table, or the merely downward velocity, and therefore the downward force is marked by the line *e a*. The body only *falls* through the distance *e a* while *moving* all the way from *e* to *c*.

162. This last figure explains the important cases to be farther considered afterwards of the force of wind on ships' sails, windmill vanes, &c.; and the oblique force of water on float-boards, water-wheels, &c.; showing that the moving mass exerts force on a surface, not in proportion to the speed with which it may be passing along or near the surface, but to the rate of perpendicular approximation. It explains, also, why the slanting blow of a club or ball is so slight, compared with the direct blow.



163. Another important case of the decomposition of forces is the determining with respect to a ball placed on an inclined plane, as at *e* upon the plane *d f*, what proportion of its weight remains unsupported by the plane, and acts therefore as a force to make it roll downwards. Now if the line *b a* be drawn from the centre of the ball to represent the whole force or weight of the ball in the direction of gravity, we may,

by the rule given in Art. 150, for completing the parallelogram, find the line *b c* or *e a*, representing the tendency along the plane, and the line *b e* representing the pressure against the plane. But *b c* or *e a* the tendency along, will be found in every possible case, to have the same proportion to *b a*, the whole weight, as the height of the plane *d g* has to its length *d f*; for the triangular figure *a b c* or *a e b*, of which the sides are the measures of the tendency and weight of the ball, is ever perfectly similar to the other triangle *f d g*, whose sides are the measures of the height and length of the plane—*b c* corresponding to *d g*, and *b a* to *d f.* A body therefore on an inclined plane, seeks to roll down with force as much less than its weight as the height of the plane is less than the length. On a plane half as high as long, a ball of one pound, to prevent its rolling down, requires a force of half a pound. Horses dragging a waggon up a steep which rises one foot in ten, lift one tenth of the load besides overcoming the friction.

"*The two great forces of Nature are* ATTRACTION *and* REPULSION." (Read the Analysis.)

164. A person, on first approaching this subject, is far from supposing that the beautiful and almost endless variety of phenomena exhibited in the universe around, are all referrible to the two principles, *attraction* and *repulsion*, examined in the first section :—but such is the truth.—It will now first be shown here, how the great classes of accelerated, retarded, and bent motions arise from them.

165. *Attraction.*—Until Newton proved, that what we call *weight* of bodies is merely an instance of that universal attraction of all matter to all matter which diminishes with increase of distance, it was never suspected that weight was less, high up in the air than on the ground; or on a lofty mountain than on the sea-shore. But this we now know to be the case. However, in studying what goes on in obedience to gravity near the surface of the earth, except in a few very nice cases, gravity may be considered there as a uniform power; for man has neither approached the centre of the earth in mines, nor receded from it in balloons, by more than about a thousandth part of his distance from it; and weight has relation to the distance from the centre, not to the distance from the surface.

"Accelerated Motion, from Gravitation."

166. Owing to the inertia of matter, any force which acts on a body free to obey it, not by one instantaneous shock, but by a continuous push or pull during a certain length of time, produces in the mass a quickening or accelerated motion; for as the motion given in the first instant or portion of time continues afterwards without any farther force, merely on account of the motal inertia, it follows, that as much more motion is added during the second instant, and as much again during the third, and so on. A falling body, therefore, under the influence of attraction, is as it were a reservoir, receiving every instant fresh velocity and momentum.

167. It is said that Newton's sublime genius first read the nature of attraction in the simple incident of an apple falling before him from a lofty branch in his garden.—The eye which perceives an apple beginning to fall, can follow it for a time and mark the gradual acceleration of its descent, but soon sees its path only as a shadowy line.

A boy letting a ball drop from his hand, can catch it again in the first instant, but after a little delay his hand pursues it in vain.

A fragment of rock, detached in any way from the brow of a hill, begins its motion slowly; but once fairly launched, it gathers fresh speed and momentum with every instant, and bounding from steep to steep drives every obstacle before it.

168. Any liquid falling from a reservoir, forms a descending mass or stream, of which the bulk diminishes or tapers from above downwards, in the same proportion as the velocity of the particles increases. This is well exemplified in the pouring out of molasses or thick syrup. If the height of the fall be considerable, the bulky sluggish mass, which first escapes, is gradually reduced, before it reaches the bottom, to a small thread; but the substance of that thread is moving proportionally faster, and fills the receiving vessel below with surprising rapidity. The same truth is exhibited on a vast scale in the Falls of Niagara; where the broad river is seen first bending over the precipice a deep gently moving mass, then becoming a thinner and a thinner sheet as it descends, until at last, surrounded by its foam or mist, it flashes like lightning into the deep below.

169. When velocity becomes considerable in any case of falling, it cannot be measured accurately by the eye, but its

effects ascertain it. A man may leap from a chair with impunity, from a table he receives a shock, from a high window he probably fractures bones, and if he fall from a balloon his body is literally dashed to pieces.

170. The term accelerating motion recalls to the common mind quickening motions to which there is soon an impassable limit; as that of a horse which walks, trots, canters, or gallops in a race, but has then done his utmost, or similarly, that of the flight of birds, the speed of a railway train, the velocity of a cannon-ball, &c., all of which soon attain their limit; but in the case of gravity acting on a body falling to the ground, there is no limit or retarding cause but the ground and air, and for every equal instant of the fall there is an equal increase of velocity. This fundamental fact could not be clearly ascertained until means were invented of accurately measuring minute portions of time, and therefore, until Galileo discovered such a measure in the swinging of a pendulum.

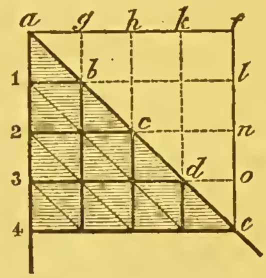
171. Careful experiment has now ascertained that the force of gravitation at the surface of this earth is such that it carries a body set free to fall, through a space of 16 feet and a fraction in the first second of time, with a velocity gradually increasing from the lowest possible at starting up to a rate of 32 feet per second at the end of the second, that is to say, a velocity which remaining afterwards uniform would carry it, without farther action of gravity, just twice as far in the next second as there had been of fall in the first. The explanation of this fact is, that the velocity of 32 feet acquired by the end of the second is only gradually acquired, the body having only half of it at the half second, and just as much less than half at any distance before that middle point as it had more than half at the same distance afterwards; the average being therefore 16 feet for the whole second.

In the next second or portion of time the body falls of course through the whole 32 feet as above noted, with 16 feet additional, from the new action of gravity, in all, three times as far as in the first second; so that in two seconds it falls altogether four times as far as in one second. At the end of two seconds the velocity attained is twice as great as at the end of one, or is of 64 feet per second, so that during the third second the body falls 64 feet, and other new 16, in all, five times as much as in the first second; and in three seconds, therefore, it has descended nine times as far as in one second, &c. Knowing this

rate of progression, the velocity acquired by a falling body, and the distance through which it falls, in any given time, are easily calculated; and the height of a precipice, or the depth of a well, may be ascertained by marking the time required for a body to fall through the space.*

172. Ordinary motions leave no permanent mark in space by which their direction and rate can be afterwards examined, as a spider spins out and leaves its thread when letting itself down from a ceiling to the floor; or as a log line unwound from its reel in a sailing ship is drawn out by the log-board cast into the still water, exactly at the rate of the ship's advance; but this last may be used to illustrate the phenomenon.

173. If 100 feet of such log-line be unreeled in a minute, these words express the speed of the ship, and if that quantity of line be then divided into one hundred equal lengths and laid down side by side, or merely folded down, on a flat surface, so as exactly to cover a square space, as here represented by *a f e* 4, it would then picture permanently to the eye a *uniform* motion of 100 feet in a minute. If that surface were then halved or cut into two equal parts by the diagonal line *a e*, the shaded half shown here *a* 4 *e* would be as true a picture of an accelerated motion, starting from rest, and attaining at the end the speed-rate of 100 feet per minute, as the whole covered square would be of the corresponding uniform motion. The fundamental truth is then intuitively perceived that a uniformly accelerating motion starting from rest and attaining any given velocity, performs just half the journey that a simply uniform motion having that velocity from the beginning, performs in the same time.



174. In relation to this diagram it is further to be observed that the vertical line *a* 4 may mark the flux of time, divided into seconds or other equal parts, 1, 2, 3, &c.; the lines from this across to *b c d e*, in breadth of the figure, mark the velocities corresponding to the ends of the times, being double for double time, triple for triple time, and so on; the number of small triangles between the stronger horizontal lines covering the area of the figure, mark how often the space described by the falling body in the first portion of time is described by it in equal subsequent portions; and the number of these triangles, counted

* See the Appendix.

from the top of the figure to any cross line, will mark how far the body has fallen at the time indicated by the horizontal line. From all this it will be understood, that in equal successive TIMES, there is increase in the following ways:

Of the VELOCITIES, as the simple numbers .	1	2	3	4	5	&c.
Of the spaces fallen through during the successive times, as the odd numbers . . .	1	3	5	7	9	&c.
And of the spaces as counted from the beginning of the fall, as the square numbers .	1	4	9	16	25	&c.

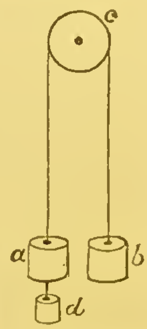
175. It will now further be understood* that while a double force of gravity would be required to cause a double extent of fall in the same time, a quadruple force would be required to cause the same extent of fall in half the time:—and that a body descending on an inclined plane where only a part of its gravity can propel it (as explained in Art. 163), will have a motion as regularly accelerated as when falling freely, only slower at first, whatever the final increase, in the same proportion as the propelling force is less than the whole weight; that is, as the height of the plane is less than its length.

176. It is interesting to reflect that a railway carriage going fifty miles an hour has the same velocity as a body at the bottom of a fall from a height of 36 feet; and the reason that all collisions on railways are not so destructive as might hence be feared, is that the shock is mitigated by the buffer springs, and during the crushing of the parts which first meet, including the break-van placed next to the engine for that purpose.

177. The doctrines of falling bodies and of accelerated and retarded motions generally are of such importance, that much attention has been bestowed upon them. Mr. Atwood's ingenious mechanical contrivance by which the motion of falling bodies may be retarded in any desired degree, without the character of the motion being otherwise altered, has enabled experimenters to render evident to the senses all that abstract calculation had anticipated. A pound weight, left quite free, falls towards the ground, sixteen feet in the first second, proving that *attraction* of one pound is just sufficient to overcome the *inertia* of one pound at that rate. But if the inertia be doubled, or tripled, or increased in any other degree, the fall of course would be just so much slower. Now Mr. Atwood's machine

* See the Appendix.

gives the powers of increasing the inertia of mass, by causing falling weights to overcome not only their own inertia, but also that of any other known weights in addition. Thus, a and b, being weights of two pounds each, balancing each other over the very easily turned pulley c, may be moved by a weight of one pound, d, hooked to one of them; and gravity in pulling this down, with force of one pound, has to overcome, not the inertia of one pound, but of five, for the other two weights must move as fast as the one pound does; and thus, the velocity being reduced to one-fifth of what is natural to a free-falling body, the descent can be minutely observed.



"Retarded Motion," from gravity.

178. What has been said of the changing velocity of a falling body, from gravity, is exactly true, in a reversed way, respecting a rising body exposed to the same influence.

179. A bullet shot directly upwards, every instant loses a part of its velocity, until at last it comes to rest in the sky,—where a soaring eagle might see the messenger of destruction motionless and harmless for a moment by his side:—the ball then descends again, and so that, at corresponding points of the ascent and descent, but for the resistance of the air, the velocities would be equal; and, on reaching the ground, it would have regained exactly the velocity with which it first departed.

180. It is explained, in a preceding paragraph, that a body falls four times as far in two seconds as in one, although the velocity at the end of the two seconds is only doubled. For the same reason, a body shot upwards with double velocity, rises four times as far as if shot with a single velocity; if shot with triple velocity, it rises nine times as far, and so forth.

In aiming for amusement at bodies thrown up into the air, it is easy to hit them near their point of turning, and more difficult always as they are nearer to the ground, whether rising or falling.

181. An upward jet of water is small below, where it issues from the pipe with great velocity, but it becomes gradually more bulky as the water loses velocity in ascending, and at the top, it often spreads a little like a tree, and any light round body will remain supported and playing upon its summit.

The rise of a clock pendulum from the bottom of its arc or

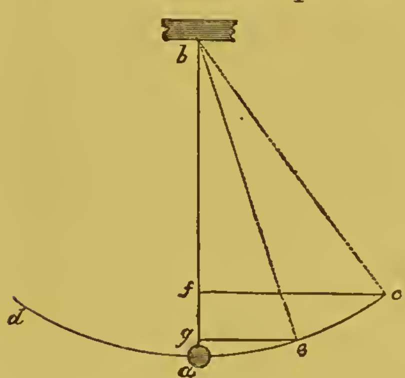
sweep is an exact copy, reversed, of its previous descent to that point.

182. "THE PENDULUM"

thus exemplifies well both accelerated and retarded motion. The name is applicable to any body so suspended that it may swing freely backwards and forwards. Such is a ball of metal hanging by a string or wire.

183. Galileo having observed the hanging chandeliers of a church ceiling to continue vibrating long and with singular uniformity, after any accidental cause of displacement, was led to investigate the laws of the phenomenon; and out of appearances which in some shape had been before men's eyes in all time, his singular sagacity extracted new knowledge of highest importance. Independently of the light which the theory of the pendulum has thrown on various branches of physical science, the instrument itself, with a few wheels attached, to record its vibrations, has now become the perfect time-keeper, and regulator of the general business of society.

184. A common pendulum consists of a ball or bob *a*, suspended by a rod of wood or metal from a fixed point *b*, and caused to swing from side to side under that point in the curve *d a c*. Being raised to *c*, and then set at liberty, it falls back to *a* with an accelerating motion like a ball rolling down a slope, and when arrived there, it has acquired just momentum enough to carry it to *d*, at an equal elevation on the other side; from this it falls back again, again to rise, and would so go on for ever, but for the impediments of air and friction.—The pendulum is an object of advanced mathematical study; but knowledge of its important characteristics may be conveyed in common language.

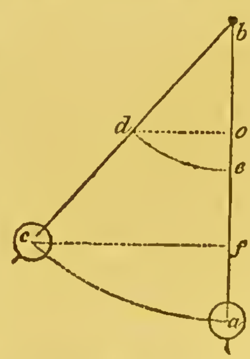


185. The *times of the vibrations* of a pendulum are very nearly equal, whether these be wide or narrow, that is, whether the arc described by it be large or small. This remarkable property is what makes it a time-keeper.—The reason that a large vibration is performed in the same time as a small one, in other words, that the pendulum always moves faster in proportion as its journey is longer—is, that in proportion as the arc

described is more extended, the steeper are its beginning and ending, and the more rapidly, therefore, the pendulum begins to fall down at first, sweeps along the intermediate space, and stops at last. It is evident, for instance, that in the above figure, the portion *c e* of the arc is much more steep, its depth being measured by the line *f g*, than the equal portion *e a* near its centre, of which the depth is measured by the line *g a*. —A pendulum made to vibrate in the curve called a *cycloid*, which, in the central part, very nearly coincides with the circular arc, but towards the extremities rises a little more steeply, has its beats perfectly *isochronous*, or in equal times, whatever their extent.

186. A common clock is merely a pendulum, with wheel-work so connected with it as to record the number of the vibrations, and with a weight or spring which has force enough to overcome the retarding effects of friction and the resistance of the air. The wheels show how many swings or beats of the pendulum have taken place, because at every beat a tooth of a wheel is allowed to pass onwards. It is evident, therefore, that a wheel which turns round once for sixty beats of the pendulum, may have a hand fixed on its axis projecting through the dial-plate, to be the seconds hand of the clock. The other wheels then are so connected with this first, by the numbers of teeth on them and on the pinions respectively, that one turns sixty times slower than the first, to fit its axis to carry a minute hand, and another by moving twelve times slower still, is fitted to carry an hour hand.

187. The *length of a pendulum* influences the time of its vibration.—Long pendulums vibrate more slowly than short ones, because, in corresponding arcs or paths, the bob or ball of the long pendulum has a greater journey to perform, without having a steeper line of descent. If a pendulum *b a* be twice as long as another *b e*, it has just twice as far to travel in its descending arc *c a*, as the other in its similar arc *d e*, while in corresponding parts of the two paths, the slope or inclination is always equal. The ball of the long pendulum, therefore, may be considered as having rolled twice as far down a given slope as the ball of the short pendulum. Now as a body falls four times as far, either directly or on any uniform slope, in two seconds as



in one (see Art. 171), a pendulum must be four times as long, to beat once in two seconds, as to beat every second. In fact, a pendulum of nearly 39 inches beats seconds; one of four times that length is required to beat double seconds, and one of one-fourth the length beats half seconds.—It is because a pendulum to answer its purpose must be of a certain invariable length, that a seconds pendulum has been proposed as an universal standard of measure.

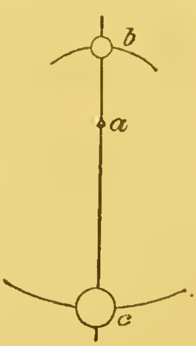
188. Because the smallest change in the length of a pendulum alters the rate of going of the clock, it is important to be able to counteract the dilatation and contraction of pendulums caused by the changing heat of the seasons; and for this purpose various ingenious means have been contrived. One of these is the *gridiron pendulum*, as it is called, from consisting of various connected rods of metal. It renders the different dilatibility by heat of the different metals composing it, the cause of unchanged length in the whole. The adjoining sketch may show that if the central rod of brass represented by the *strong* line from *b* to *c*, dilate alone upwards, just as much as the two rods of steel, represented by the *weaker* lines on either side of the brass, dilate together downwards, (the expansion of brass by heat being about double that of steel,) it will exactly counteract the lengthening of these, and will keep the ball *d* always at the same distance from the point of suspension *a*. Another device for this purpose is to substitute for the solid ball or bob at the bottom, a deep and wide tube of quicksilver, and then as the pendulum rod expands downwards by heat, the mercury expands upwards, as in a common thermometer, and the contrary movements balance each other. Some astronomical clocks in the present day are so perfect, that they scarcely err one beat of the pendulum in a year.—Common clocks are regulated by a screw which lifts or lets down the ball of the pendulum, and so changes the effective length, which is, the distance between the point of suspension and what is called the *centre of oscillation*, treated of in the next chapter.

189. The *force* of gravity is what determines how long the pendulum is in falling to the bottom of its arc, and therefore also how long in rising,—for the ball of the pendulum may be considered as a body descending by its weight on a slope. A change in the force of gravity, therefore, would at once alter the rate of all the clocks on earth. At the equator of our earth,

where the gravity of bodies is counteracted in a small degree by the centrifugal force arising from the earth's motion (as explained at page 51), a pendulum vibrates more slowly than elsewhere, and must therefore be made shorter to answer the same purpose. Corresponding results take place when a pendulum is carried to a mountain top, and therefore farther away from the centre of the earth,—or when carried to the bottom of a mine, where it is attracted by the matter above it, as well as by the matter beneath.

190. The erroneous popular notion (see Art. 143), that a large or heavy body should fall to the earth, even in a vacuum, more quickly than a small or light body, attaches itself also to the case of a heavy and a light pendulum. But there is no difference for pendulums of the same length, whatever their weight or material, but what depends on the resistance of the air. This is proved by making the bob hollow, and changing the nature and quantity of its contents. It is a very remarkable fact thus further proved, that in all substances the gravity and inertia perfectly correspond.

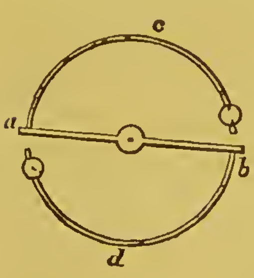
191. There is a small pendulum called a *metronome*, used by musicians for marking time; which, although very short, may still be made to beat whole seconds, or even longer intervals. The reason of its slow motion is, that its rod is prolonged upwards, to *b*, beyond its axis of support, at *a*, and has a ball upon the top, at *b*, as well as on the bottom, at *c*; which upper ball prevents the under one from moving so fast as it otherwise would, just as a smaller weight attached to one end of a weighing-beam, prevents a greater weight attached to the other end from falling so fast as it would if there were no counterpoise. The rate of motion changes with any change in the distance of the ball *b* from the centre of motion *a*; and to allow of such change, the ball *b* is made to slide at will.



192. A pocket-watch differs from a clock, in having a vibrating wheel instead of a vibrating pendulum; and as, in a clock, gravity is always pulling the pendulum down to the bottom of its arc, which is its natural place of rest, but does not fix it there, because the momentum acquired during its fall from one side is just sufficient to carry it up to an equal height on the other—so in a watch, a spring, generally spiral, surrounding the axis of

the balance-wheel, is always drawing this towards a middle position of rest, but does not fix it there, because the momentum acquired during its approach from either side to the middle position, carries it just as far past on the other side, and the spring has to begin its work again. The balance-wheel at each vibration allows one tooth of the adjoining wheel to pass onwards, as the pendulum does in a clock, and the record of the beats is preserved by the wheels which follow, as already explained for the clock. A main-spring is used to keep up the motion of a watch, instead of the weight used in a clock; and as a spring acts equally whatever be its position, a watch keeps time although carried in the pocket, or in a moving ship.

193. As the rate of a clock is influenced by the length of its pendulum, so is the rate of a watch by the size or diameter of its balance-wheel; and heat which retards the motion of a common clock by lengthening the pendulum, retards the motion of a common watch by dilating the balance-wheel. Ingenuity, however, has found a remedy for the latter case as for the former, *viz.* the contrivance called the *expansion balance-wheel.* Of this the circumference, instead of being a continuous ring, is made up of two half-rings, as *c* and *d*, each attached by one end only, viz. *c* at *a*, and *d* at *b*, to a cross bar *a b*, and which half rings being composed of brass on the convex side, and of steel on the concave, bend or curl inwards by heat—as a sheet of damp paper bends when held to the fire—and thus for the time diminish the size of the wheel at their free extremities, so as just to counterbalance its increase at the fixed extremities by the expansion or lengthening of the cross bar.



As the motion of a pendulum has relation to the *force of gravity*, so has the motion of the balance-wheel to the *stiffness of the balance-spring;* and the regulator of a watch is merely a pin which bears against the balance-spring, and by sliding backwards and forwards, so as to shorten or lengthen the parts of the spring left free to act, changes the degree of its stiffness.

194. It would be exceeding the limit marked out for this general work, to speak more particularly here of those admirable watches which have been produced within the last century under the name of *chronometers,* for the purpose of ascertaining the longitude at sea; but the author may perhaps be excused

for referring to a moment of intense pleasure, if not of surprise, which in early life he experienced on a particular occasion, in having their singular perfection actually proved. After months spent in a tedious passage from South America to Asia, his pocket chronometer (which he still wears) enabled him one morning to compute that a certain point of land was then bearing east from the ship at a distance of fifty miles. In an hour afterwards, when a mist had cleared away, the looker-out on the mast gave the joyous call of "Land ahead!" verifying the indication of the chronometers on board almost to a mile, after a voyage of thousands. It is natural at such a moment, with the dangers and uncertainties of ancient navigation before the mind, to exult in contemplating what man's ingenuity has now achieved. Had the rate of the wonderful little instrument in all that time changed but a little, its announcement would have been worse than useless—but in the night and in the day, in storm and in calm, in heat and in cold, while the persons around it were experiencing every vicissitude of mental and bodily condition, its steady beat went on, keeping exact account of the rolling of the earth among the stars; and in the midst of the trackless sea, it was always ready to declare its wondrous secret of the exact moment of time then marked by the Observatory clock at Greenwich, thereby revealing the very spot of the globe over which it had arrived. The mode of using a chronometer for so valuable a purpose will be explained in the section on astronomy.

195. *Bent or curvilinear motion from attraction.*—This takes place whenever attraction is acting across the path of any otherwise free motion. The flying cannon-ball or stone, drawn down to the earth by gravity, is an example; for the projectile force ceases with the first impulse, but the bending force is acting every instant, and by every instant producing a new effect causes a curvilinear path.

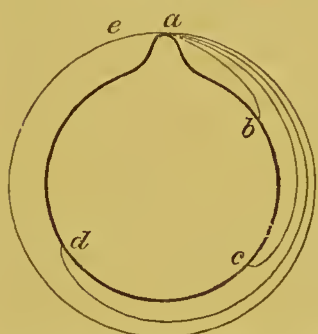
196. An oblique jet of water is to the eye a permanent exhibition of the curve described by a body thus projected. The particles of the liquid move in the line which they would describe if projected singly, and the continued succession of them marks the line of situations through which each passes in its course to the earth.

197. A cannon or musket ball, shot quite horizontally over a level plain, will touch the ground or plain just as soon as

another ball dropped at the same instant directly from the cannon's mouth; for the forward or projectile motion does not, in such a case, at all interfere with the action of gravity (Art. 155). This result, which most persons, before consideration, would be disposed to doubt, makes strikingly sensible the extraordinary speed of the cannon-ball; *viz.* that it has already moved perhaps six hundred feet forward, during the half second that a ball dropped from near the cannon's mouth requires to reach the earth only four feet beneath. The fact also explains why, for a long range, the gun must be pointed more or less upwards.

A dozen marbles swept horizontally from off a table by a long stick, all reach the floor at the same instant, how different soever the distances to which they may respectively be driven.

The detailed study of the subject of projectiles is very important to military engineers; and we know how successfully they have pursued it, by the precision with which they now direct their shot and shells to objects at very great distances.



198. A cannon-ball shot horizontally from the top of a lofty mountain, might go five or six miles. (The mountain is here, for the purpose of illustration, represented on an enlarged scale, as standing on the globe *b*, *c*, *d*, at *a*.) If there were no atmosphere to resist its motion, or if the mountain top were above the surface of the atmosphere, the same original velocity would carry it forty miles or more before it fell, as to *b*: with more force still, it would reach to *c*, and with still more to *d*. And if it could be despatched with about ten times the velocity of a common cannon-shot (Art. 138), it would not have approached nearer to the earth than at first, when it had again reached round to *e* or even to *a*; and its velocity being still undiminished, it would perform a second similar tour, and then a third, and so forth: it would, in fact, have become a little satellite, or planetary body, revolving round the earth. In the successive ranges represented in the figure, it is seen that the centrifugal force of the ball, or its tendency to move in a straight line, becomes more and more nearly a counterbalance to gravity, and at last is exactly equal to it. If the force given to the ball were more than sufficient to bring it round again to the level of *a*, the effect would be, not its departure from the earth, but the orbit changed from circular to oval or elliptic, like that of a

comet. There may be many such revolving masses above our atmosphere, although invisible to us, owing to their smallness and distance, as explained under ASTRONOMY.

199. REPULSION,—produces *accelerated, retarded,* and *bent* motions, like attraction, but it acts chiefly at minute distances, while *attraction* draws from the sun, or from the very limits of the universe. *Repulsion* acts, for instance, between the adjoining atoms of an elastic fluid. Repulsion, however, plays a very important part in the economy of nature. We have already seen, when considering the constitution of masses in *section first*, that repulsion prevents or modifies the contact of the atoms of all bodies; that with increase of temperature, it causes these atoms to separate, and converts a solid into a liquid, or even into an air; that it operates round all masses as if it were a film or covering, preventing their mutual cohesion, &c.

200. *Accelerated* motion from repulsion, is seen when the atoms of gunpowder explode and propel the bullet from the bottom of a piece to the muzzle with such rapidly increasing velocity. The strength of this repulsion of gunpowder is so much greater than the strength of gravity or common attraction, that its action on a bullet, during the passage along a barrel of five or six feet in length, may not be overcome by gravity, during an ascent of a mile or more.

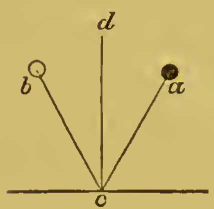
A visibly *retarded* motion from repulsion, is exemplified by a moving body coming against a spring or a cushion full of air, or against the piston-handle of an air-syringe, so as to compress the air beneath it.

Any elastic body striking against another body and recoiling, exhibits in succession the phenomena of retardation, acceleration, and often also of bending, chiefly from repulsion: for instance:

201. An ivory ball driven forcibly against a marble slab, does not stop at the instant that apparent contact takes place, but still advances and compresses that part of its substance which is against the marble,—as is proved by the facts mentioned at page 30. While this compression of the ivory and marble is going on, the resistance made by the increasing repulsion of the particles gradually retards, and ultimately destroys the forward motion of the ball; and at the instant of its final arrest, the parts in contact, both of the ball and of the marble, being in their greatest degree of compression, act on the ball, and repel

it again with gradually accelerating motion, until it leaves the marble, with the same velocity which it had on approaching. The retardation and acceleration take place here within so small a space, and in so short a time, that they are not apparent to sense; but the mind perceives the nature of the phenomenon as distinctly as if the ball had rolled against the end of a long steel spring.

202. If the ball strike the marble obliquely, as from *a* to *c*, in a path forming the angle *a c d* with a perpendicular line, it



does not rebound in the same line by which it approached, but just as obliquely towards the other side, *viz.* from *c* to *b*; and it then exhibits a bent motion from repulsion. This case illustrates also the "resolution of motions," for the oblique descent *a c* being composed of a direct downward motion from *a* to the table, and a horizontal or forward motion from *a* towards the perpendicular, the table destroys the downward motion and converts it into an opposite directly upward motion; but it does not effect the forward motion, which immediately combines again with the upward, and carries the ball as far beyond the perpendicular at *b* as it was distant from it at *a*. The important law in physics, of which this is an example, is usually expressed—"The angles of incidence and of reflection, or of approach and recoil, are equal." It applies to all reflected bodies, as balls, waves, sound, light, &c.

203. Collision between hard bodies always exhibits more or less of the truth now described: when it occurs between soft bodies, as lumps of lead or of moist clay, the approaching parts mutually displace each other, and there is no recoil.

When a straight steel plate, of which the end is fixed in a block, is bent, as by a ball rolling against it, the particles on the side which becomes concave are made to approximate, and there is a resistance or repulsion gradually increasing among them; the particles on the convex side, again, are drawn a little more from each other, and are therefore exerting attraction to return: the recoil of the spring is thus owing to both forces trying to replace the particles in their former relative situations.

"*Tides, Winds, &c. exemplify* ATTRACTION." (Read the Analysis, page 35.)

204. Until we reflect attentively on this subject, we are far from perceiving that nearly all the phenomena of nature are but instances of *attraction* and *repulsion*, acting on *inertia* under variety of circumstances.

205. ATTRACTION.—*Tides* are raised by the attraction of the moon and sun acting on the water beneath them, and they fall again by the general attraction of the earth when these bodies disappear, producing in many of the shallower parts of the ocean very rapid horizontal currents. They do a great deal of work for man. They carry his ships along the coasts, and up and down the rivers; they turn water-wheels for him; they fill his docks and canals at convenient times; they rise to receive his ships, launched from elevated building yards, &c. What a busy scene is a great sea-port river, during the rising and falling of the tide—with the thousands of people along its banks, borrowing assistance in their various occupations!

Winds are produced chiefly by the fluid atmosphere seeking its level, in obedience to the attraction of the earth, after the action of distürbing causes, such as the heat of the sun, &c. They help man in the important business of *navigation;* they turn his windmills, &c.

206. *The Currents* of rivers, are water constantly descending on slopes, that is, seeking its level, in obedience to the earth's attraction. Water-mills and inland navigation are among the advantages which they afford to man.

All falling and pressing bodies exhibit attraction in its simplest form.

REPULSION—is instanced in *explosion*, the formation of *steam*, the action of *springs, &c.*

Explosion of gunpowder is repulsion among its particles when assuming the form of air.

Steam, by the repulsion among its particles, forces along the piston of the steam-engine. In the present day it performs much more than half the labour of society.

Accidental explosions of fire-damp or hydrogen in mines, and the tremendous evolutions of elastic fluid in volcanoes and earthquakes, are other instances of the same class.

Elasticity, as seen acting in springs, collision, &c. belongs

chiefly to repulsion; as seen in India-rubber, and other substances resuming their usual length after expansion, it belongs chiefly to attraction.

A spring is often rendered a reservoir of force, kept ready charged for a purpose; as when a gun-lock is cocked, a watch wound up, &c.

207. It will be remarked, with respect to many of the phenomena now and hereafter to be mentioned, that it is not the original Attraction or Repulsion which man uses as his servant, but the momentum gradually accumulated in masses by the exertion of such attraction or repulsion.

Electrical, *galvanic*, and *magnetical* phenomena, are also in great part peculiar attractions and repulsions, as will be seen in the chapters devoted to the explanation of them. And even the *actions of animals*, so infinitely varied, are mostly results of a shortening of the fleshy threads called muscular fibres, which is produced by the mutual *attraction* of their component particles; —just as the varied motions of a ship's yards are produced by the shortening of certain ropes of connexion.

However closely allied the last-mentioned forms of attraction and repulsion may be to the general attraction and repulsion formerly treated of, it is found convenient to consider them apart.

208. In the remarkable phenomena of nature and art, the motions being caused, as now shown, by Attraction and Repulsion, these forces do not operate by a single impulse, but through a repetition of impulses, or a continued action, of which the effect is gradually accumulated in the inertia of matter. Thus nearly all great velocities and momenta are the results of accelerated motion.

Meteoric stones, coming from great heights, bury themselves deep in the earth by the force of their gradually acquired velocity.

209. When the wood-cutters among the Alps launch an enormous tree from high on the mountain side, along the smooth wooden trough or channel prepared for it, and in fewer minutes than it traverses miles, it is seen plunging into the lake below; it acquires its terrific final velocity, not at once, but through the action of gravity continued during the whole time of its descent.

The shock or blow of the ram of a pile-engine is not the effect of momentary attraction between it and the earth, but of that attraction accumulating motal inertia or power, during the descent of the ram through a space of twenty feet or more.

210. A common hammer, in its instantaneous shock, has the condensed effect of the arm and of gravity, as accumulated through its whole previous course; and when a powerful blow is intended, the hammer, or hatchet, or club, or fist in boxing, is lifted high, or carried far back, that there may be time and space for imparting greater power.

211. The inferior animals, by many of their actions, illustrate the same truth, and prove their experimental or instinctive acquaintance with it.

Sea birds carry shell-fish up into the air, and drop them on smooth stones to break them, and to obtain the food. It is related in Grecian story, that a bird once mistook the venerable bald head of a sage meditating on the sea-shore for a smooth stone, and by the same act killed an oyster and the philosopher.

There are some long-necked birds, that fight and kill their prey by a blow of their hard beak. They draw back the head, bending the neck like a swan or serpent, and then dart it forward, with a continued effort, until the strong wedge-like beak reaches its destination, almost with the velocity of a pistol-bullet.

212. Bulls, rams, and goats, in fighting, alternately recede and then run at each other, that the shock may be great when their foreheads meet.

A horse in kicking, from the great length of his leg, and the consequent space through which he can be adding velocity to his foot, drives it at last against the object almost like a cannon-shot.

A bow-string propelling an arrow, follows it through a considerable space, and so gives the great velocity at last produced.

213. A sling gives to the hand the power of adding velocity to a stone through a long path; for the hand moves in a small circle while the stone moves in a larger, and being kept always somewhat in advance of the stone, pulls at it without intermission, until the moment of discharge.

The battering rams of the ancients allowed those about them to accumulate in them the efforts of many hands, and of a considerable duration of action, so as to give at last one great and sudden shock.

214. Even the gentle action of the human breath, exerted for a time on a pea or small hard ball of clay while passing through a long smooth tube, gives a velocity which will kill a small animal. In Borneo and others of the Eastern Islands, poisoned arrows are thrown in this way with great force and precision.

215. The action of gunpowder on bullets, although appearing so sudden, is still not an instantaneous, but a gradual, and therefore accelerating action; and accordingly we find the effect to depend much on the length of the piece along which the force pursues the ball. A small fast-sailing vessel with a single long gun, has compelled a superior vessel, whose guns were shorter, to yield.

For the same reason that all great velocities require continued action or repeated impulse to produce them, so do they also to destroy them; the inertia of motion and of rest being exactly equal.

216. A vast mass of rock suspended like a pendulum, and caused to sweep down its curve from a considerable elevation, would arrive at the bottom like a battering ram, with force sufficient to shake a thick wall or rampart to its foundation. The continued action of gravity would have given this force, and if, instead of the solid resistance supposed, and which would scarcely be sufficient to take the whole momentum away, the mass were merely allowed to continue its course as a pendulum, and to ascend on the other side, the continued action of gravity then opposing its motion, would bring the great mass to powerless rest again, by the time when it had reached an elevation equal to that from which it fell.

217. It is soft gas expanding which gives gradually the death-carrying velocity to the cannon-ball; and soft air, or cotton, or wool, resisting in a close strong tube,—if the bullet could be directed exactly into it—would again gradually annihilate the motion. Were the attempt made, however, to stop the ball suddenly, by a block of the hardest granite, the block would be shivered by the force.

218. Bales of cotton or thick masses of cork, attached round a ship, will receive cannon-balls, and bring them to rest, without themselves suffering much, while the naked firmer side of the ship would be penetrated. The cotton or cork offers an increasing resistance through a considerable space, while the oak opposes its hard front at once, and must instantly suffice or be

torn. A hard body, that it may at once destroy such a motion as we are supposing, must be able to oppose as much force in perhaps the space of one hundredth of an inch, that is, in the extent to which its elasticity will let it yield without breaking, as the moving cause gave, through a much greater space (a plate of steel will thus oppose a pistol bullet); and when it cannot do this it must be broken or penetrated by the moving body.

Innumerable experiments have been made within a few years to ascertain how far ships or land fortifications can be secured against the action of the more powerful artillery of recent invention, by plates or other forms of iron. A wall, roof, or ship's side, if completely protected, is called ball or bomb-proof.

219. A hempen or silken elastic rope supporting the scale of a weighing beam, would resist a greater weight *falling* into the scale than would be resisted by an iron chain which were stronger than the rope for the purpose of bearing a *quiescent* weight: because the hemp or silk would yield by its elasticity, and continue its resistance through a considerable space and time, and thus would at last gradually overcome the momentum; while the iron, by scarcely yielding at all, would require to be strong enough to stop the mass at once, or would break.

220. Yet for the same reason that iron is weakest in such a case as the last, it is stronger than hemp or rope when used as a chain cable for a ship, to withstand the sudden force of waves. This will be understood on considering, that the chain by its weight hangs as a curve or inverted arch in the water, while the rope being nearly of the weight of water, is supported in it almost as a straight line from the anchor to the ship; therefore, when a great wave dashes against the ship, the bent chain will be resisting until it be drawn nearly straight, by which great extent of yielding, and consequent length of resistance, it will withstand and overcome a great force; whereas the straight rope, as it can yield only by the elasticity of its material, and comparatively, therefore, a little way, will resist much less.

221. A heavy ship moving quickly with the tide or wind, could not be stopped instantly by a short rope or chain of any magnitude: if the attempt were made to destroy at once so vast a momentum, something would certainly give way; but a rope of very moderate size, kept tight between the shore and the ship, and from time to time allowed to slip a little round a

wooden block, when the tightness threatened its breaking, would accomplish the end very soon and safely.

222. The following are further proofs that forces are to be measured as much by the time or space through which they act, as by their difference of intensity or momentary power.

223. A door standing open, and which would yield readily on its hinges to the gentle push of a finger, is not moved by a cannon-ball swiftly shot through it. Yet the ball really overcomes the whole force of cohesion among the atoms of tough wood: but that force is allowed to act or resist for so short a time, owing to the rapid passage of the ball, that it is not sufficient to affect the inertia of the door, so as to produce sensible motion. The cohesion of the circle in the door, cut out by the ball, might have borne a weight of more than a hundred pounds laid quietly upon it; but supposing the bullet to fly twelve hundred feet in a second, and the door to be one inch thick, the cohesion being allowed to act for only the 14,400th part of a second, its influence is not perceived. The following are other examples of the same kind.

224. A leaden bullet pressed slowly against a pane of glass, cracks and breaks it irregularly, where the strength happens to be least; but the same bullet shot at it from a pistol, makes only a small round hole. It has been amusingly said of such a case, that the particles struck and carried away, have not had time to warn their neighbours of what was happening.

225. A cannon-ball, having very great velocity, passes through a ship's side, and leaves but a little mark; while one with less speed splinters and breaks the wood to a considerable distance around. A near shot thus often injures a ship less than one from a greater distance, or with a smaller charge of powder.

A sheet of paper bent to stand edgeways on a table, may not be driven down by a pistol-ball fired through it.

The truth at present under consideration explains, with respect to gun-shot wounds, why the sufferer often remains ignorant for a time of his misfortune, and why a rapid bullet only kills the parts which it touches, while a spent ball may bruise and injure widely around. In many cases of injury, popularly attributed to the *wind of a ball,* the ball has really touched the part.

226. A man lying down and receiving the blow of a great

hammer on his chest, would be killed by it; but if a heavy anvil be first laid upon the chest, and the blow be given upon that, the man bears it with impunity. Here the quantity of motion in the hammer, being diffused through the great mass of the anvil, produces but a trifling velocity, which the elasticity of the chest, in its slow yielding, safely overcomes.

227. A circular plate of soft iron, made to whirl or spin with extreme rapidity, will cut through the hardest steel file, almost as a knife cuts through a carrot. In cases where a soft powder spread on the rim of a wheel suffices to polish a hard body, it acts partly like this plate, by the motion or velocity given to the wearing particles.

"*There is no motion or action in the universe, without a concomitant and opposite action of equal amount.*" (See the Analysis.)

228. This truth has otherwise been expressed—" action and reaction are equal and contrary."—It is evident, that if no action or movement takes place on earth but in consequence of either Attraction or Repulsion, as is shown above, there must always be two objects or masses concerned, and each must be *attracted* or *repelled* just as much as the other, although one will have less velocity than the other in proportion as it may be greater, or be fixed to another mass.

229. If a man in one boat pull at a rope attached to another, the two boats will approach. If they be of equal size and load, they will both move at the same rate, in whichever of the boats the man may be; and if there be a difference in the sizes and resistances, there will be a corresponding difference in the velocities, the smaller boat moving the fastest.

230. A magnet and a piece of iron attract each other equally, whatever disproportion there is between the masses. If either be balanced in a scale, and the other be then brought within a certain distance beneath it, the very same counterpoise will be required to prevent their approach, whichever be in the scale. If the two were hanging near each other as pendulums, they would approach, and perhaps meet; but the little one would perform more of the journey in proportion to its littleness.

231. A man in a boat pulling a rope attached to a large ship seems only to move the boat: but he really moves the ship a little; for, supposing the resistance of the ship to be just a thousand times greater than that of the boat, a thousand men in

a thousand boats, pulling simultaneously in the same manner, would make the ship meet them half way.

A pound of lead and this earth attract each other with equal force; but that force makes the lead approach sixteen feet in a second towards the earth, while the contrary motion of the earth is as much less than this as the earth is weightier than one pound,—and is therefore unnoticed. Speaking strictly, it is true, that even a feather falling lifts the earth towards it, and that a man jumping kicks the earth away.

A spring unbending between two equal bodies throws them apart with equal velocity; if between bodies of different magnitudes, the velocity of the smaller body is greater in proportion to its smallness.

232. On firing a cannon, the gun recoils with even more motion or momentum in it than the ball has, for it suffers the reaction of the expelled gunpowder as well as of the ball; but the momentum in the gun being diffused through a greater mass, the velocity is small, and easily checked.

The recoil of a light fowling-piece may hurt the shoulder, if the piece be not held close to it.

A ship in chase, by firing her bow-guns retards her motion; by firing from her stern she quickens it.

A ship firing a broadside, heels or inclines to the opposite side.

233. A vessel of water suspended by a cord hangs perpendicularly; but if a hole be opened in one side, so as to allow the water to jet out there, the vessel will be pushed to the other side by the reaction of the jet, and will so remain while it flows. If the hole and jet be oblique, the vessel will constantly turn round.

A vessel of water placed upon a floating piece of plank, and allowed to throw out a jet, as in the last case, moves the plank in the opposite direction.

A steamboat may be driven by making the engine pump or squirt water from the stern, instead of making it, as usual, move paddle-wheels. There is a great loss of power, however, in this mode of applying force, as will be explained under the head of "Hydraulics."

A man floating in a small boat, and blowing strongly with a bellows towards the stern, pushes himself onwards with the same force with which the air issues from the bellows pipe.

234. A sky-rocket ascends, because after it is lighted the

lower part is always producing a large quantity of aëriform fluid, which, in expanding downwards, presses not only on the air below, but also on the rocket above, and thus lifts it. The ascent is aided also by the recoil of the rocket from the part of its substance, which is constantly bursting downwards.

235. He was a foolish man who thought he had found the means of commanding always a fair wind for his pleasure-boat, by erecting an immense bellows in the stern to fill the sails. The bellows and sails acted against each other, and there was no motion: indeed, in a perfect calm, there would be a little backward motion, because the sail would not catch all the wind from the bellows.

A man supported on a floating plank, by walking towards one end of it gives it a motion in the direction opposite.

A man using an oar, or a steam-engine turning paddle-wheels, advances exactly with the force that drives the water astern.

A swimmer pressing the water downwards and backwards with his hands, is sent forwards and upwards with the same force, by the reaction of the water.

And a bird flying is upheld with exactly the force with which it strikes the air in the opposite direction.

A man pushing against the ground with a stick may be considered to be compressing a spring between the earth and the end of his stick, which spring is therefore pushing him up as much as he pushes down; and if, at the time, he were balanced in the scale of a weighing beam, he would find that he weighed just as much less as he were pressing down with his stick.

236. Thus an invalid, sitting on a spring plank or chair, who by an intermitting downward pressure of his hand on a staff or on a table, causes his body to rise and fall through a considerable range, and thus obtains the advantage of almost passive exercise, is really lifting himself while he presses downward.

The difference of momentum acquired in a fall of one foot or of several is well known: the corresponding intensities of reaction are unpleasantly experienced by a man who sits down in an easy chair, or who, in sitting down where he supposed a chair to be, unexpectedly reaches the floor.

237. What motion the wind has given to a ship it has itself lost, that is to say, the ship has reacted on the moving air: as is seen when one vessel is becalmed under the lee of another.

238. When one billiard-ball strikes directly another ball of equal size it stops, and the second ball proceeds with the whole

velocity which the first had—the action which imparts the new motion being equal to the reaction which destroys the old. Although the transference of motion, in such a case, seems to be instantaneous, the change is really progressive, and as follows. The approaching ball, at a certain point of time, has just given half of its motion to the other equal ball, and if both were of soft clay, they would then proceed in contact with half the original velocity; but, as they are elastic, the touching parts at the moment supposed are compressed like a spring between the balls, and by then expanding, and exerting force equally both ways, they double the velocity of the foremost ball, and destroy altogether the motion of that behind.

239. If a billiard-ball be propelled against the nearest one of a row of balls equal to itself, it comes to rest as in the last case described, while the farthest ball of the row darts off with its velocity—the intermediate balls having each received and transmitted the motion in a twinkling, without appearing themselves to move.

240. As further illustrative of the truths, that action and reaction are equal and contrary, and that in every case of hard bodies striking each other, they may be regarded as compressing a very small strong spring between them, we may mention, that when any elastic body, as a billiard-ball, strikes another body larger than itself, and rebounds, it gives to that other, not only all the motion which it originally possessed, this being done at the moment when it comes to rest, but an additional quantity, equal to that with which it recoils—owing to the equal action in both directions of the repulsion or spring which causes the recoil. When the difference of size between the bodies is very great, the returning velocity of the smaller is nearly as great as its advancing motion was, and thus it gives a momentum to the body struck nearly double of what it originally itself possessed. This phenomenon constitutes the paradoxical case of an effect seeming greater than its cause, and has led persons, imperfectly acquainted with the subject, to seek from the principle a *perpetuum mobile.* A hammer on rebounding from an anvil has given a blow of nearly double the force which it had itself; for the anvil had felt its full original force while stopping it, and then, equally with itself, was affected by the repulsion which caused its return.

Many other interesting facts might be adduced as examples of equal action and reaction, but these may suffice.

This second section of the work has now explained the nature of INERTIA in matter, and has shown that the infinitely varied phenomena of motion, which the universe exhibits, are only *attraction* and *repulsion,* acting on the *inertia* of *atoms* separate or conjoined, under diversified circumstances.—And such is the sublime simplicity of the whole scheme of nature.

PART II.

THE PHENOMENA AMONG SOLIDS;

OR,

THE STATES OF MOTION AND REST WHICH DEPEND ON THE *SOLID* FORM OF BODIES: A DEPARTMENT COMMONLY CALLED *MECHANICS OF SOLIDS.*

ANALYSIS OF THE CHAPTER.*

A force, which moves part of a solid body, must affect the whole or break off the part.

If the force be directed towards a certain central point in the mass, it will affect the whole equally, whether simply to support the mass, or to move it, or to stop it when in motion. That point, according to circumstances, is called the CENTRE OF GRAVITY, OF INERTIA, *or* OF ACTION.

In solid bodies moving about a centre or axis, as exemplified in a wheel or weighing beam, the various parts describe circles or move through spaces, which are greater in proportion to their respective distances from the centre of motion. Hence forces differing as to speed, may still, through a solid medium, be brought exactly to co-operate or to oppose one-another —a slow force counterbalancing or being equivalent to a quicker one, provided that it be more intense in proportion as it is slower. The SIMPLE MACHINES, *or* MECHANICAL MEDIA, *called* LEVER, WHEEL AND AXLE, PULLEY, INCLINED PLANE, WEDGE, SCREW, *&c., are so many arrangements of solid parts, by which forces of different velocities and intensities may be thus connected or opposed, or may be conveniently substituted one for another.*

By solid connecting parts also the direction of any existing motion or force may be changed, as when the straight motion of running water is converted into rotatory motion of a water-wheel. Hence arises an endless variety of COMPLEX MACHINES.

In all machines, an important circumstance to be considered is the resistance among moving parts which arises from FRICTION:—*and in solid structures generally, the forms and positions of parts have to be adjusted to the* STRENGTH OF THE MATERIALS, *and to the strains which the parts have to bear.*

* The reader should here re-peruse the *general view* or *synopsis* at page 1.

"*Solid*" is the term applied to a mass in which the mutual attraction of the atoms is so strong, that the mass may be moved about as one body, without the relative positions of the component parts being thereby disturbed.

"Force moving part of a solid must affect the whole or break off the part."

This is a necessary consequence of the description or definition of a solid just given. And it follows that in all cases of breaking, the cohesion of the atoms at the fractured part must have been less strong than—1st, the weight of the remaining mass; or, 2ndly, its inertia resisting the degree of change attempted; or, 3rdly, the force fixing it to its place; or, 4thly, than some combination of these particulars.

The sharp blow of a hammer given on the side of an ivory ball, causes it to dart off swiftly, but does not injure it, because the cohesion among the atoms struck is stronger than the opposing inertia of the mass, even under a rapid change: but such blow of the hammer on a large elephant's tusk indents or breaks the part, because the opposing inertia of the larger mass is stronger than the cohesion of the particles which receive the blow.

241. A vessel of pottery-ware may be safely suspended by its handle; proving that the cohesion which fixes the handle to it is stronger than the weight of the vessel and its contents; but if the attempt be made to lift the vessel quickly, the handle may rise and leave the body behind; because then the weight and inertia are acting together to destroy the cohesion. Thus servants attempting to lift too quickly the loaded stone-ware dishes at a dinner-table, may break off the part by which they take hold.

" Centre of Gravity or Inertia."

242. If any uniform beam or rod be supported by its middle, like a weighing beam, the two ends will just balance each other. This is in accordance with the general truth or law of *attraction* already explained; for as there is just as much similarly situated matter on one side of the support as on the other, there will also be just as much downward attraction, and therefore no reason why the matter on one side should overpower that on the other. If equal weights be afterwards attached in corresponding situations on the two arms of the beam, the balance will not be thereby disturbed; and the operation of adding weights that counterpoise, above and below, and near and far from the

centre, may be continued, until a bulky mass is built up upon the beam, (and instead of a beam a wheel may be used,) yet the whole will remain perfectly supported and in equilibrium about the original centre. In the pages now to follow, it will be shown that, in every body or mass, or system of connected masses, in the universe, there is a point of this kind about which all the parts balance or have equilibrium, and it is this point which is called the *centre of gravity* or of *inertia.* Although in any mass, therefore, every atom has its separate gravity and inertia, and the weight and inertia of the whole are really diffused through the whole, still by supporting this one point, either from above or from below, the whole mass is equally supported; by lifting it, the whole is lifted; by stopping it, the whole is brought to rest; and when it rises or falls, the general mass is really rising or falling. Thus for many purposes a body, however large, may be considered as compressed into or existing only in the single point called its *centre of gravity* or of *inertia.*

This centre in a mass of regular shape and of uniform substance, as a ball or cube of metal, is easily found, because it is the evident centre of the form; but in bodies that are irregular, either as to density or form, it must be found by rules of calculation, hereafter explained.

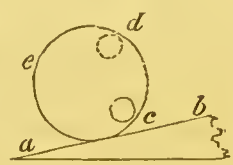
243. To say that the centre of gravity will always take the lowest situation which the support of the body will allow, is thus only to repeat, that bodies tend by their gravity towards the centre of the earth. In a suspended body, therefore, as the lowest situation which the centre of gravity can find is, when it is immediately under the point of suspension, all bodies hanging freely must have their centre of gravity directly under that point. A plummet is an interesting example of this; and the truth furnishes in many cases of irregular masses, a very simple practical mode of finding the centre.

244. Thus if an irregular piece of plank or of pasteboard, represented here by the figure *a e b d*, be suspended from any point, as *a*, and the cord of a plummet *a g* be attached at the same point, the centre of gravity of the board must be somewhere near the direction of the plummet, and a chalk line made on the board where the cord touches it, must pass over the centre of gravity. If the board be then suspended by another point, as *d*, and another chalk line *d e* be made in the same manner, the place *c*, where

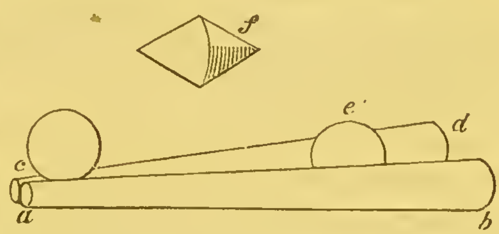
the two lines cross or cut each other, will indicate the centre of gravity; and the board, when supported by a cord attached there, will hang evenly balanced.

The following cases further illustrate the truth, that the centre of gravity always seeks the lowest place. They seem at first to be exceptions to the law; but when more fully considered, are interesting proofs of it.

245. A wooden cylinder or roller *e d c*, placed on a slope or inclined plane *a b*, will naturally roll down, because, its centre of gravity is thereby approaching the earth; but if there be a heavy mass of lead *c* introduced at one side, which must rise before the roller can descend, the rise of that mass being contrary to gravity, the motion of the roller will be arrested. Indeed, if the roller were placed on the plane with the lead in the high position *d*, the lead would fall down to the position *c*, and so would move the roller towards *b*, exhibiting the singular phenomenon of a body rolling up hill by the action of its weight.

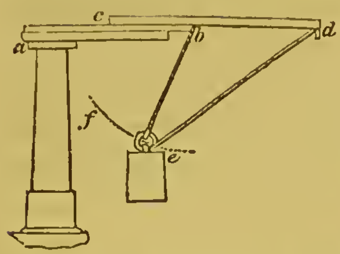


246. If a billiard-ball *c* be placed upon the small ends of two billiard sticks or cues *a b* and *c d*, laid on a table with their points *c* and *a* in contact, but with the larger ends *b* and *d* so far apart that there may be just room for the ball to touch the table between them, the ball will roll along between the cues, sinking gradually from its high situation near their points, to its lower situation near *b*. To a careless observer, it would then have the appearance of rolling upwards, because the cues on which it rests are thicker towards the ends *d* and *b*; but it would really be descending in obedience to gravity. If a double cone, as represented at *f*, were substituted for the ball, it would similarly roll from *c* to *e*, and with still more of the fallacious appearance of rolling upwards, because its ends would always be resting on the upper and rising surfaces of the cues.



247. The board or stick *c d* resting on the edge of the table *a b* would naturally fall if left to itself, because more than half of it is beyond the edge of the table; but strange to say, an additional weight *e* attached to its projecting part as at *b* by the cord *b e*, instead of pulling it down faster, shall fix or steady

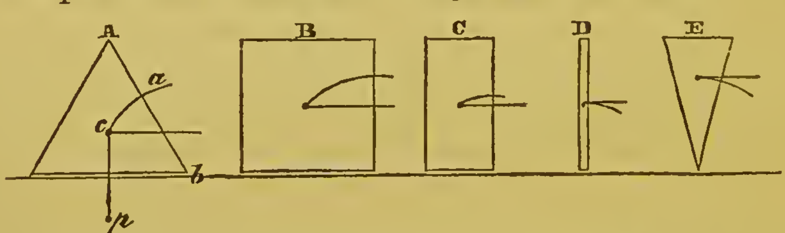
it on the table, provided the weight be pushed inwards a little



by a rod *d e* resting against it and against a niche in the stick at *d*. It is evident that the stick *c d*, in falling, must turn round the edge of the table at *b*; but in so doing, after the arrangement here supposed, it must lift the weight *e* along the path *e f*—which rise, as the weight is heavier than the stick (that is to say, as the common centre of gravity of the connected objects is near *e*), gravity forbids, and therefore the stick and weight will both remain supported by the table. An umbrella or walking cane, hanging on the edge of a table by a crooked handle, is another instance of the same kind. And the common toy of a little man standing on tiptoe upon the top of a pillar, and supporting two leaden bullets by wires descending from his hands, is another combination of parts which places the centre of gravity of the whole below the support, making the combination a kind of pendulum.

By attending to the centre of gravity of the bodies around us on earth, we are enabled to explain why, from the influence of gravity, some of them are stable or firmly fixed, others tottering, others falling.

248. If we find that a body, from its form or position, cannot be pushed over or upset without its centre of gravity being lifted,—knowing now that the general mass is then lifted in the same degree, we see why a weak cause cannot effect the change. The rise of the centre of gravity, or body, in any case of overturning, where the centre of gravity is over the middle of the sustaining base, will be proportioned to the breadth of the base of the body, compared with the height of the centre of gravity above the base. This is shown in the annexed figures, in which the two particulars of *base* and *height* are combined in a series



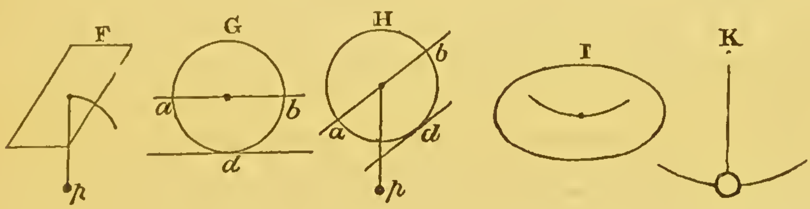
of proportions. In the figures the dot *c* marks the place of the centre of gravity, and the curved line beginning from the dot

marks the path of that centre, when the body is being overturned. This curved line is a portion of a circle which has the edge or extremity of the base (*b*, in fig. A) as a centre, because the body in turning must rest upon such extremity or corner as the centre of its motion. The further inwards, therefore, from this extremity that the centre of gravity is, as marked by where a plumb line as *p*, hanging from it, crosses the base, the further of course is the centre of gravity from the top of the circle which it has to describe in moving, and the steeper, consequently, will be its commencing path; and as in the case of bodies when forced upwards on slopes, the steeper the ascent, the greater will be the force necessary to give motion.—The line of a plummet hanging from the centre of gravity is called the *line of direction* of the centre, or that in which it tends naturally to descend to the earth.

249. In fig. A, which has a broad base and little height of the centre of gravity, we see that the centre must rise almost perpendicularly before it can fall over, and the resistance to overturning is therefore nearly equal to the whole weight of the body. Hence the firmness of a pyramid.

In figures B, C, and D, progressively, the commencing path of the centre is less and less steep, because the base is narrower, and hence the bodies are so much the less stable. B may represent an ordinary house, C a tall narrow house, and D a lofty chimney.

Fig. E shows a tottering position, for the centre of gravity being directly over a base which is a mere point, the least inclination to either side places it on a descending slope, and the body must fall.



In F the position is tottering on one side, and stable on the other. This explains how the least inclination of a standing body virtually narrows, in one direction, its sustaining base.

In G, which represents a ball upon a level plane, the whole mass is supported on a single point as in E, yet the body has no tendency to move, because in any other possible position the

centre would still be as far from the sustaining plane. In moving, the centre describes the straight level line *a b*.

In H the ball is on an inclined plane, and rolls down, the centre of gravity describing the oblique line *b a*.

In I, which is an oval body resting on a level plane, when the body is moved to either side, the centre of gravity must rise a little, as in the case of a pendulum. Hence an oval body rolling on a level will have the motion of its centre somewhat like that of a pendulum.

K is a true pendulum whose centre of gravity describes the curve here shown; as explained in the first chapter, (Art. 184.)

The importance of the subject of the centre of gravity will be further judged of by the facts which are now to be reviewed.

250. A cart loaded with metal or stone may go safely along a road of which one side is higher than the other, as here shown,

but were the same cart loaded with wool or hay it would be overturned; because, although the sustaining base be the same in the two cases, the *line of direction* falls much within it from the low centre of gravity of the metal at *c*, but falls very near the wheel at P, or altogether on the outside, from the high centre of the wool at *a*, and in the latter case the centre has offered to it a descending path.

251. This explains why lofty stage coaches or vans are so dangerous, and particularly when heavy luggage is placed on the top, and why lofty gigs and curricles have led to so many fatal accidents. As regards any of these, a defect of smoothness or of level in the road, or even, in a case of quick driving, a slight lateral bend, often suffices to produce the catastrophe.

252. A similar disaster of lamentably frequent occurrence is exhibited, when in a small boat unskilful passengers, on some alarm, start suddenly to their feet, instead of retaining their safe low seats, and so upset the boat by altering its trim or balance.

253. The feet or legs of tripods are generally expanded below, to give a broad base. The same is true of common chairs; but a thoughtless child often leans so far over the back of a chair, as to cause the line of the general centre of gravity to fall beyond the base, and the chair with its load is overturned backwards. The small lofty chairs made to raise children to the

parent's elbow at the dinner-table, are dangerous if the feet are not made to spread considerably. Pillar-and-claw tables, candlesticks, table-lamps, and many other articles of household furniture, have stability given by widening tho base.

254. The least inclination of a standing body virtually narrows the supporting base on the side to which the body leans.

This truth is explained by fig. F. It shows the necessity of building the thin walls and tall chimneys of modern houses perfectly upright. And hence the extreme importance and utility of that simple instrument the *plummet* or *plumb-line,* which when applied to a body, is a visible indication respecting the line of gravity. The mason and many other workmen cannot proceed a step without their guiding plummet.

The brick walls of houses in towns are often so thin, that, to have standing strength, they require to rest against one another; and hence they occasionally exhibit only the kind of stability which belongs to a child's house built of cards. They form a striking contrast to some masses of masonry which remain to us from antiquity, resting on firm-spreading basements. What magnificent illustrations of strength and durability dependent on proportions are the remains of ancient pyramids and temples, which still give such interest to the banks of the Nile, and to valleys and plains of Asia!

255. There are many remarkable structures on earth which are known to lean or incline a little, from fault in the foundations: yet so long as the line of their centre of gravity remains within the base, and the parts of the mass have coherence sufficient to hold them together, the structure will stand. The famous tower of Pisa, with a height of 188 feet, overhangs its base sixteen feet, and assumes nearly the air of fig. F, in page 91.

256. An oval body on a flat level surface, as already explained by fig. 1, page 91, oscillates somewhat like a pendulum, because when disturbed from its middle position, its centre of gravity has risen and seeks to return. The same is true of any regular slice or portion of a solid globe, which will consequently always come to rest with its plane face turned directly upwards.

The rocking-horse of children and the common cradle are exemplifications of the same class.

257. Other curious instances are those rocks called Loggan or Laggan stones, of which there are several among the rocky barriers of the British coast. An immense mass, loosened in some convulsion of nature, is found with a slightly convex base resting on a flatter surface of rock below, and so nearly balanced, that the force of a man suffices to move it. Some of these have been objects of superstitious veneration to their neighbourhood.

258. There is an amusing Chinese toy, made in accordance with the same principle. It has the appearance of a little fat laughing man, sitting on the ground with his feet concealed under his clothing; but where the feet should be, there is only a rounded smooth surface, with heavy lead ballast placed in it, so low as always, when allowed, to raise the body to the erect or sitting attitude. A child pushes the little fellow down again and again, and would persuade him to lie still, but is surprised to see him always up the moment after, shaking about as lively as ever.

259. The vibratory motion of a pendulum, as dependent upon the circumstance of the centre of gravity having been moved from its lowest place which it again constantly seeks, was so fully considered in the last chapter, that it need not be again dwelt upon here; but we have to enumerate the following phenomena as being of the same class.

The vibrations of the common swing, seen at fairs.

The rocking of a balloon when it first ascends.

The spontaneous shutting of those gates or doors of which the upper hinge is made to overhang or project beyond the lower. Such a gate always returns of itself, from either side, to the shut position, just as a pendulum returns to the lowest part of its arc: the gate in fact is a sloping pendulum.

260. Of the same nature also is the rocking or rolling of a ship, in a rough sea. When the centre of gravity of a ship is too low, owing to much of its heavy load being placed near the keel, this pendulum-motion, in rough weather, becomes excessive and dangerous.

The actions and postures of animals, and particularly of man, illustrate beautifully the observations made above with respect to the centre of gravity.

261. A body, we have seen, is tottering in proportion as it

has great altitude and narrow base—but it is the noble prerogative of man to be able to support his towering figure with great firmness, on a very narrow base, and under constant change of attitude. This faculty is acquired slowly because of the difficulty. A child does well who walks at the end of ten or twelve months; while the young of quadrupeds, which in their four feet have a broad supporting base, are able to stand and even to walk and run very soon after birth.

262. The supporting base of a man is the space occupied by and included between the outer edges of his two feet. The advantage of turning out the toes moderately is, that without taking much from the length of the base, it adds considerably to the breadth.

If there be much art in walking on two perfect feet, it is evident how inadequately the substitutes of two slender wooden legs with rounded extremities can serve, as in the cases of mutilated soldiers and sailors.

Yet all the ladies of the empire of China have to acquire nearly the same talent as these victims of war; for barbarous custom has crippled them, by confining their feet for life, in shoes which prevent growth.

263. But surpassing in difficulty any of these instances is the practice, which is general among the inhabitants of the sandy plains called the *Landes*, in the south-west of France, of walking on stilts. The *Landes* afford tolerable pasturage for sheep; but during one portion of the year are half covered with water, and during the remainder are still very unfit walking-ground, by reason of the deep loose sand and thick furze. The natives meet the inconveniences of all seasons by doubling the length of their natural legs, through the addition to them of the stilts mentioned, which they call *des échasses.* Mounted on these, which are wooden poles, put on and off as regularly as the other parts of dress, they appear to strangers a new and extraordinary race of long-legged beings, marching over the loose sand, or through the water, with steps of six or eight feet in length, and with the speed of a trotting horse; a possible journey being of thirty or forty miles in a day. While watching their flocks, they fix themselves in convenient stations, by means of a third staff which supports them behind, and then with their rough sheep-skin cloaks and caps, like thatched roofs over them, they appear like little watch-towers, or singular lofty tripods, scattered over the face of the country.

Still beyond the art of walking on stilts is that which some persons attain of walking and dancing on a single rope or wire; or even of keeping the centre of gravity above the base, while standing on the moveable support of a galloping horse.—A rope-dancer has to carry a long pole in his hand, to balance him: it is loaded at each end, and when he inclines, he throws it a little towards the side required, that the reaction may restore his perpendicularity.

Much art of the same sort is shown in the attitudes and evolutions of the skater; in the amusements of supporting a pole upright on the end of the finger; and in other feats of a like kind.

264. *Attitudes* generally depend on the necessity of keeping the centre of gravity of the body over the base under variety of circumstances, as in—the straight or upright port of a man who carries a load on his head;—the leaning forward of one who carries it on his back;—the hanging backwards of one who bears it between his arms;—the leaning to one side of him who is carrying a weight on the other side;—the habitual carriage of very fat people, with head and shoulders thrown back, giving a certain air of self-satisfaction,—an air which belongs also to the expectant mother, and even to the dropsical patient, although producing in the latter so sad an incongruity.

When a man walks or runs, he inclines forward, that the centre of gravity may overhang the base: and he must then be constantly advancing his feet to prevent his falling. He makes his body incline just enough to produce the velocity which he desires.

A man, in pulling horizontally at a load, is merely causing his body to overhang its base, so that its tendency to fall forward may become a force or power applicable to the work.

265. When a man rises from a chair, he is seen first to bend the body forward, or to draw the feet backward, so as to place the feet or base under the centre of gravity, and then he lifts the body up. If he lift too soon, that is, before the body is sufficiently advanced, he falls back again.

266. A man standing with his heels close to a perpendicular wall cannot, without falling, bend forward sufficiently to pick up any object that lies before him on the floor; because the wall prevents him from throwing part of his body backward, to counterbalance the head and arms which have to project forward. A person little versed in such matters might agree to pay

heavily for permission to possess himself, if he could, of a purse of money, laid on the ground before him: he of course would lose his stake.

When a man walks slowly, his centre of gravity comes alternately over the right and over the left foot, as seen still more strikingly in the waddle of a duck. This is the reason why the body advances in a waving line, and why persons walking arm in arm shake each other, unless they make the movements of their feet to correspond, as soldiers do in marching.

267. *Sea sickness* is a subject closely related to the present. Man requiring, as now explained, to maintain strictly his perpendicularity, that is, to keep the centre of gravity always over the supporting base, ascertains the required position in various ways, but chiefly by comparing the perpendicularity, or other known position of things about him, with his own position. Vertigo, and sickness, are often the consequences of depriving him of his standards of comparison, or of disturbing them.

Hence on shipboard, where the lines of the masts, windows, furniture, &c., are constantly changing directions, sickness, vertigo, and other affections of the same class, are common to persons unaccustomed to ships. Many persons experience similar effects in carriages, and in swings; or on looking from a lofty precipice, where known objects being distant, and viewed under a new aspect, are not so readily recognized; also in walking on a wall or roof; in looking directly up to a roof, or to the stars in the zenith, because then all standards disappear; on entering a round room, where there are no perpendicular lines of light and shade, as when the walls and roof are covered with a paper which has no regular arrangement of spots; on turning round, as in waltzing, or if placed on a wheel—because the eye is not then allowed to rest long enough on any standard, &c.

268. People when in the dark, and therefore blind people always, use standards connected with the sense of touch; and it is because, on board of ship, the standards both of sight and of touch are lost, that the effect is so remarkable.

But sea sickness depends partly also on the irregular pressure of the internal organs among themselves and against the containing parts, when the influence of their inertia and weight varies with the rising and falling of the ship.

From the nature of sea sickness, as discovered in these facts, it is seen why persons unaccustomed to the motion of a ship

often find relief by keeping their eyes directed to the fixed shore, where visible; or by lying down on their backs, between supports, and shutting their eyes.

269. As no condition or form of matter escapes from the great laws of nature, we find the attitudes and general state of vegetable as well as of animal bodies, characterized by the necessity of having the centre of gravity supported over the base. With what admiration may we contemplate the pine and other trees in the forests of nature, springing up towards the zenith as perpendicularly as if the plummet were at work to direct them; and not less on the sides of precipitous hills than in the level plains. On a smaller scale, we see the grasses and corn-stalks of our fields, illustrating the same truth. And whenever, in tree or shrub, accident or peculiar nature causes a deviation from perpendicularity, additional strength and support are provided.

270. *Beauty of form or position* is often felt to belong to bodies, merely because they possess the shape and support required, that the centre of gravity may be stable.

In architecture, how displeasing to the eye of an observer is a wall or pillar that is not quite upright; or a column with too small a base; or a very tall narrow house; or a long slender chimney. On the other hand, how beautiful in a lofty edifice is the suitable succession of columns, from the massive Doric of the basement, supporting the whole superstructure, to the light Corinthian or kindred forms seen above. The Chinese pagoda is a fine example of the union of the requisites for stability, namely, perpendicularity and expanding base, with the other qualities of perfect symmetry, graceful proportion, and fanciful ornament. When seen in its own country, crowning a rising ground in a wooded island, or springing up from the centre of any rich landscape, it forms perhaps as beautiful an object as fancy has imagined.

271. *Beauty of attitude* and *grace of carriage* in the human individual, are in great part referable to the same principle.

The postures of opera dancers might pass as intentional illustrations of the number of ways in which the centre of gravity may be kept above a narrow base, by counteracting one disturbing motion or extension of a limb by some opposite and corresponding motion. The common statue of the god Mercury on

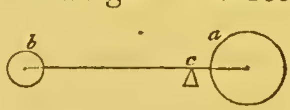
tiptoe is a permanent familiar illustration of such a beautifully balanced attitude.

Grace of carriage includes not only a perfect freedom of motion, but at the same time a steady bearing of the centre of gravity over the base. It is usually possessed by those who live in a hilly country, taking much and varied exercise, or who make gymnastics a part of their discipline. Great is the contrast between the gait of the active mountaineer and that of the mechanic or shopkeeper, whose confinement to the cell of his trade soon produces in his body a shape and air corresponding to it:—and in the softer sex what a difference is there, between that strong and graceful fair one who recalls to us the fabled Diana of old, and that other sedentary being, who having scarcely trodden but on smooth pavements or carpets, carries her person, under any new circumstances, as if it were a load new and foreign to her.

The *centre of gravity* is also the *centre of inertia.*

272. When a person lifts a uniform rod or bar by its middle, the inertia of both ends being equal, he overcomes it equally, and raises them evenly together. When he lifts by a part nearer to one end, the shorter and lighter portion having less inertia will rise the first, and there will be a turning motion of the rod round the support, proportioned to the excess of weight in the greater side.

273. The *centre of gravity*, or *inertia*, however, is not necessarily in the centre of the mass;—for if a weight of three pounds, *a*, be affixed to one end of a rod, and a weight of only one pound, *b*, be affixed to the other, the two will still be balanced, if supported or lifted by a point of the rod, *c*, three times nearer to the centre of the large weight than to the centre of the small one. This fact is explained under the head of *lever*, a few pages hence. For the sake of simplicity, in describing such experiments, the weight of the connecting rod itself is neglected.



274. The *centre of gravity* or *inertia* is also the *centre of centrifugal force:*—for if the balls *a* and *b* of the last figure were made to spin round a common centre, as by making the connecting rod rest and turn upon a point or pivot at *c*; unless the point *c* were the centre of inertia of the two, the pivot would always be drawn in the direction of that end of the rod at which

the centrifugal force were the greatest. It is on this account that in the case of a millstone, or great fly-wheel, or of the balance-wheel of a watch, the axis must pass through the centre of inertia, to prevent its being more worn on the one side than on the other.

275. When we say, in astronomy, that the earth revolves round the sun, or that the moon revolves round the earth, we do not speak with absolute correctness, for in all such cases, both bodies are revolving round the common centre of inertia of the two. In the case of the sun and earth, as the former is about a million times larger than the latter, the common centre of inertia of the two is a million times nearer to its centre than to the centre of the earth, and is therefore within its body or circumference.

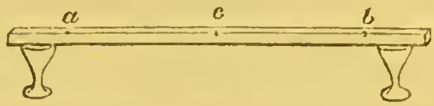
276. The *centre of inertia* in a body moving evenly, is also its *centre of action* or *percussion ;* because, if such centre come against an obstacle, the whole momentum of the body acts there and is destroyed; while, if any other part than the centre hit, the body loses only a part of its momentum, and then revolves round the obstacle as a pivot or centre of motion, that side advancing on which the greater inertia happened to be.

277. In a hammer, or a bar of iron used as a hammer, or in a pendulum, the momentum is not equally diffused through the whole, for the velocity of different parts is different, being greatest far from the hand or centre of motion; and the centre of all the motal inertia is nearer to the fast moving end than to the other. Its exact place, in many cases, is easily ascertained by calculation. In a uniform rod swinging as a pendulum, for instance, it is at the distance of one-third from the lower end. In a pendulum it is called the *centre of oscillation.*

278. If a man use a bar or rod of iron as a hammer, he must take care to make it strike the object by its centre of action, or his own hand will receive a part of the shock. A very heavy mass thus carelessly used will seriously strain the wrist. In a common hammer, as the chief part of the matter is at the end, the centre of percussion is there too, and no precaution of the kind just mentioned is required.

279. If a rod or small log of wood be suspended horizontally by a string tied to its middle, or be floating in water, and if a forward blow be given directly across it near to one end, the other end will be found, in the first instant, to have moved a little backward, or in a direction contrary to the blow, as if the

rod had been fixed upon an axis. The inertia of the general mass, by resisting the motion, becomes in effect a fixed axis. This truth is amusingly illustrated by laying the ends of a long stick on two wine-glasses and then breaking the stick by a smart downward blow of a poker on its centre. Instead of

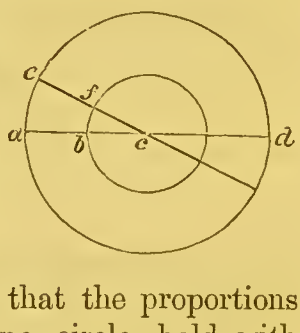


breaking the glasses also, as by such a blow might be expected, the ends of the stick rise at the instant of the stroke, to turn round certain *centres of resistance* in the fragments, as at *a* and *b*, and then fall harmless on the table.

In this *section* we have seen what admirable simplicity is given to many of our reasonings and operations by considering bodies in reference only to their *centre of inertia,* under one or other of its names.

"*In a solid body moving about a centre or axis, like a wheel or weighing-beam, the different parts have different velocities, according to their respective distances from the axis or centre.*" (Read the Analysis.)

280. The truth of this proposition is perceived at once on comparing the motion in the rim of a wheel, or near the ends of a weighing-beam, with that in parts nearer the centres. Suppose *a d* to be a line drawn across a wheel, or along a weighing-beam, the centre of motion in either case being at *c*; then the outer circular line or path *a c*, which a point at *a* describes when moving, is longer than the corresponding inner line, *b f*, which a point at *b* describes in the same time, as *a* is further from the centre than *b*.



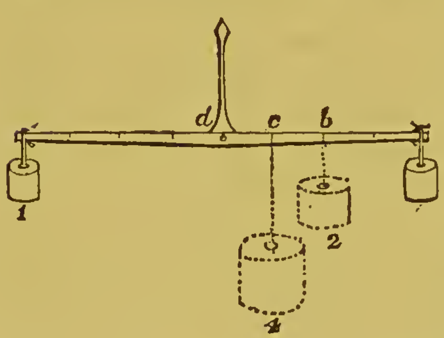
This is merely an instance of the truth, that the proportions existing between any parts or lines in one circle, hold with respect to the corresponding parts and lines in all circles. (See the Appendix.)

281. "*Hence forces with different speed may still be placed in continued connexion or opposition; and they will balance or be equivalent, if the one be as much more intense than the other as it is slower.*" (Read the Analysis.)

282. This is the important truth upon which the science of mechanics may be said to hinge. It gives to man the *simple*

machines or *mechanical powers*, as they have been called,—the Lever, Wedge, Pulley, &c., which enable him to adapt any species and speed of power which he can command, to almost any work which he has to accomplish: and the discovery of it, and of means to apply it, may be said to have subjected external nature to his control. His works are of a thousand kinds, from the displacing of a rock to the spinning of a delicate thread; while the natural powers or forces at his command are chiefly wind, waterfalls, fire, and animal effort—and of which in any particular case he may have only one kind at his service;—still, being able to connect together his power and resistance by solid media, of which different parts move with any desired difference of velocities, he can employ any force, for a purpose of almost any kind.

283. There is, however, a false and very misleading notion very generally existing with respect to the *simple machines,* which we must begin by removing, *viz.* that they *increase the quantity* of power or force applied to them. For instance, when one pound at the end of a beam or lever, is seen just balancing two pounds, at *b*, at half the distance on the other side of the axis, or four pounds, as *c*, at a quarter of the distance; many persons believe that the lever itself gives or begets a force equal to the difference of the weights so balanced. But we shall now show, that levers and all the other *mechanical powers* (as from the erroneous idea above mentioned they have been called), merely enable us to make such substitutions, as that of a small weight descending far, in place of a greater weight descending a little way, or of an inferior force working long, instead of a superior force working for a shorter time,—and thus often to accomplish ends to which the particular force possessed would be unsuited if applied directly.

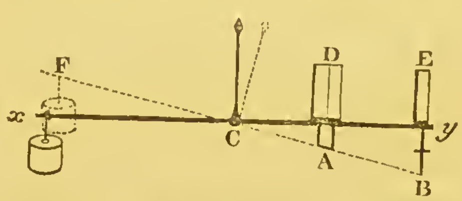


284. In other words, the simple machines enable us to concentrate or divide any kind or quantity of force which we possess, so as to suit it to our various purposes, just as mill-ponds and branching channels enable us to accumulate or divide the force of a stream of water; but they no more increase the *quantity of power* than a mill-pond increases the quantity of

water. When any slender force is caused, through a machine, to produce some effect which seems proportioned to an intense force, it has always to act longer, or through more space than the other, just in proportion as it is more slender; as a small stream of water acting for ten minutes, may produce the same effect as a gush ten times as great can in one minute. Twenty feet of the action of a small horse near the circumference of a great wheel, may be rendered, by intervening machinery, equivalent to ten feet of the action of a heavy ox or elephant nearer the centre. And one horse in drawing through six hundred feet, or a hundred horses in drawing through six feet, or the piston of a great steam-engine, in rising once from the bottom to the top of its cylinder, &c., may all be made to do the same work.

285. The apparent paradox of a weight of one pound at the end of a beam (as represented by the last figure) being rendered through such medium equal in effect to that of four pounds placed nearer the centre at *b*, is solved by reference to the nature of inertia of motion explained at page 52. The same amount of force which gives any certain velocity to four pounds is just that required to give four times the velocity to one pound; and owing to the connection of the two weights through the beam no motion downwards by gravity can occur in the four pounds without causing a motion upwards just four times as great in the one pound. These two effects being equal and directly opposed to each other, must exactly balance, and no motion whatever of the beam will be produced.

286. To illustrate this subject further; we shall suppose a weighing-beam *x y*, with a weight of one pound hanging at the end *x*; then if a spring issuing from the fixed box at E, with uniform force of one pound, be made to push at the other end of the beam *y*, it will just balance the weight; and if it be in the slightest degree stronger than the weight, it will push the end of the beam *y* down to B, we may suppose two inches, and will raise the weight to F. If, instead of the single spring of one pound at the end of the beam, two such springs be applied at half-way from the centre, so as to press at A, where there is just half the extent of motion, or room to act, as at B, exactly the same effect will follow. Now because one



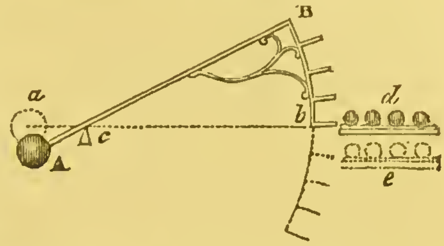
spring at the end of the beam, is seen here doing the same work as two similar springs, or a single spring of double strength at the middle, it might at first appear that there were a saving of power by using the single spring and longer lever; but let it be observed, that the two middle springs have each issued from their box only one inch, while the single spring at the end has issued two inches: in both cases, therefore, exactly two inches of one-pound spring have been used.

287. In the last experiment, pound weights or little buckets of water might be used instead of the springs, and with exactly the same result—one pound or pint at the end of the arm producing the same effect as two pounds or pints at the middle of it: but it would be observed that the single quantity fell two inches, while the double quantity at half distance fell only one inch; and to replace them after they had done their work, there would evidently be the same labour, whether a person had to lift the single quantity first one inch, and then another, or had to lift, first, one half of the double equipoise an inch, and then the other half as much.—Each atom of matter may be considered as held to the earth by its thread of attraction, and if one atom rise or fall ten inches, just as much of the supposed thread of attraction will be drawn out or returned as if ten atoms rise or fall one inch. And so, where a weight of one pound is made to do any work, instead of a weight of two pounds, there is no more saving than in giving away two yards of single rope instead of one yard of double rope; and in like manner for all other differences of intensity.

288. If a man were to exert a force of one hundred pounds at A, in the above figure, to lift the weight, a boy at B, with force of fifty pounds, might do just the same work; but the man would only have worked or pressed down through one foot, while the boy would have worked through two; and therefore, although the boy with the assistance of the lever, seemed to become as strong as the man, the case would merely be, again, that of the one-pound spring unbending two inches, to produce an effect equal to that of the two-pound spring unbending one inch. The boy would be using two feet of his smaller force, where the man used one foot of his greater force; and if the work had to be long continued, the boy would have completely exhausted himself when the man remained yet fresh.

289. A case of the lever, exhibited in this diagram, serves well to explain the nature of *mechanical powers* in general.

Suppose A to be a weight of four pounds at the end of a rod or lever A B, made to turn on *c* as an axis or fulcrum, and having the arm *c* B four times as long as the arm *c* A (but the two arms of the lever being equipoised so as not to disturb the action of weights subsequently attached to them); then one pound at the end B, would balance the four pounds at the end of A, and with the slightest additional weight would preponderate. Now let us suppose the arc B *b* to have been fixed to the long arm of the lever with the four projections or shelves here shown, on which balls of one pound each might rest; then if one of the four balls from the plane *d* were to roll upon the first shelf, it would just balance A, and, with one grain more, would descend to the level of the plane *e*, one inch below, and thence roll off; while a second ball of one pound would occupy the second shelf, and would descend in the same way, to be followed by a third, and afterwards by a fourth; and when the whole four had fallen from *d* to *e*, they would just have lifted the four-pound mass, at the other end of the lever, one inch. So that, although one pound were seen here lifting a weight of four pounds, it would only have lifted that one-fourth part as far as it fell itself, and the sum of the phenomenon would be, that four pounds, by falling one inch at the long end of the lever, had raised four pounds through the same distance of one inch at the short end. No *mechanical power* or *machine* generates force more than the lever does in this case.



290. It appears, then, from all this, that as the *quantity of motion* in a body is measured by its velocity and the number of atoms in it conjointly, so the *quantity of force* exerted in any case, is measured by the *intensity* of the force conjointly with the *space* through which it moves. A clear mode, therefore, of comparing forces, is to state conjointly the *lengths* and the *intensities*—for instance, to speak of ten feet of one-pound force as equal to one foot of ten-pound force, &c.

291. A horse pulling with the force of fifty pounds goes generally at the rate of six miles an hour; the steam-engine piston is generally made to move at the rate of two hundred feet per minute, bearing a pressure of steam of about twenty pounds to each square inch of its surface; a particular mill-stream may have a force of one hundred pounds, with a velocity

of a hundred and fifty feet per minute:—now it is easy, by simple arithmetic, and the rule of *length* and *intensity* above explained, to compare all these and other forces as applicable to any given work. We must warn the reader, however, that there are many important considerations connected with the practical employment of forces, according to their respective nature and that of the resistance to be overcome, which cannot be entered upon in this elementary work. In very many cases there is a great waste or unavoidable loss of force, because the resistance, in yielding, runs away or escapes from the force; as when a ship runs away from the wind which is driving her, or the floats of a quick-moving water-wheel, from the stream which turns it. Horses drawing boats or carriages at the rate of five miles an hour, may exert great force, but to have a speed exceeding twelve miles they might require nearly their whole effort to move their own bodies. As a general rule, although *equal quantities* of force balance each other when applied to parts of a lever or wheel altogether or nearly at rest, still when a force is made to act near an axis or fulcrum, to produce considerable velocity in a more distant part of the machinery, much of it is wasted in friction and in pressure against the fixed fulcrum.

292. What an infinity of vain schemes—and some of them displaying great ingenuity—for perpetual motion, and new mechanical engines of power, would never have come into notice, had the great truth been generally understood, that no form or combination of machinery ever did or ever can increase, in the slightest degree, the amount of power applied. Ignorance of this is the hinge on which most of the dreams of mechanical projectors have turned. No year passes, even now, in which many patents are not taken out for such supposed discoveries; and the deluded individuals, after selling perhaps even their household necessaries to obtain the means of securing the expected advantages, often sink in despair, when their attempts, instead of bringing property and happiness to their families, end in disappointment and ruin. The frequency, and eagerness, and obstinacy, with which even talented individuals, owing to their imperfect knowledge of this branch of natural philosophy, have engaged in such undertakings, is a remarkable phenomenon in human nature. Examples of such schemes will be noticed in different parts of this work, where they may serve to illustrate points under consideration.

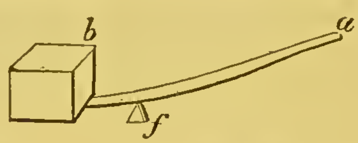
"*Lever, wheel and axle, &c.*" (Read the Analysis, at page 86.)

These are the simplest of the contrivances, which the circumstance of solidity in masses has enabled man to adopt, for the purpose of connecting or opposing forces and resistances of different intensities. We proceed to describe them, and to explain some of their useful applications.

"*Lever.*"

A beam or rod of any kind, resting at one part on a prop or axis, which becomes its centre of motion, is a lever; and it has been so called, probably, because such a contrivance was first employed for lifting weights.

293. This figure represents a lever employed to move a block of stone: *a* is the end to which the *power* or *force* is applied, *f* is the *prop* or *fulcrum*, and the mass *b* is the *weight* or *resistance*. According to the rule already given and explained at page 101, the power may be as much less intense than the resistance, as it is farther from the fulcrum, or moving through a greater space. A man at *a*, therefore, twice as far from the prop as the centre of gravity of the stone *b* is, will be able to lift a stone twice as heavy as himself; but he will lift it only one inch for every two inches that he descends: and two men would be required, acting at half the distance, to do the same work.



There is no limit to the difference, as to intensity, of forces which may be made to balance each other by the lever, except the length and strength of the material of which levers have to be formed. Archimedes said, "Give me a lever long enough, and a prop strong enough, and with my own weight I shall lift the world." But he would have required to move with the velocity of a cannon-ball for millions of years, to alter the position of the earth by a small part of an inch.

294. To calculate the effect of a lever, in practice, we must always take into account the weight of the lever itself, and the fact of its bending more or less; but in expounding the theory of the lever, it is usual to consider first, what would be the result, if the lever were a rod without weight and without flexibility.

295. The rule for the lever, that the opposing forces, to balance each other, must be more or less intense, exactly as they act nearer to or farther from the centre, holds in all cases,

whether the forces be on different sides of the prop or both on the same side, and whether the force nearest to the prop have the office of power or of resistance; it holds also, whether the lever be straight or crooked, provided the forces act at right angles to the direction from the fulcrum.

The following are examples of levers with the prop between the forces.

296. The *handspike*, represented in page 107, is a lever moving a block of stone. The same form when made of iron, with the extremity formed into claws, is called a *crow-bar*. Both kinds are used by gunners in moving cannon during battle: they are also used generally for lifting and moving heavy masses through small spaces, as the materials of the mason, the ship-builder, the warehouseman, &c. A short crow-bar is the instrument used by housebreakers for wrenching open locks or bolts, tearing off hinges, &c.

297. The common *claw-hammer*, for drawing nails, is another example. A boy who cannot exert a direct force of fifty pounds, may yet by means of this kind of hammer extract a nail to which half a ton might be quietly suspended without drawing it, because his hand moves through perhaps ten inches, to make the nail move a small part of an inch. The claw-hammer also proves that it is of no consequence whether the lever be straight or crooked, provided it produces the required difference of velocity between power and resistance. The part of the hammer resting on the plank is the fulcrum.

298. *Pincers* or *forceps* consist of two levers, of which the hinge is the common prop or fulcrum. In drawing a nail with steel forceps or nippers, we have a good example of the advantages of using a tool: 1. The nail is seized by the teeth of steel instead of by the soft fingers: 2. Instead of the griping force of the extreme fingers only, there is the force of the whole hand conveyed through the handles of the nippers: 3. The force is rendered many times more effective by the lever-length of the handles: and 4. By making the nippers, in drawing the nail, rest on one shoulder as a fulcrum, it acquires all the advantages of the lever or claw-hammer for the same purpose.

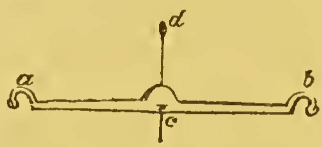
299. *Common scissors* are also double levers, as are also those stronger *shears* with which, under the power of a steam-engine, bars and plates of iron are now cut as readily as paper is cut by the force of the hand.

The common *fire-poker* is a simple lever. It rests on the bar of the grate as its prop, and displaces or breaks the caked eoal behind as the resistance.

300. The *mast of a ship*, with sails set upon it, acts sometimes as a long lever, having the wind filling the sails as the power, turning upon the centre of buoyancy of the vessel as the fulcrum, and lifting the ballast or centre of gravity as the resistance. For this reason lofty sails make a ship heel or lean over greatly, and if used in open boats, are dangerous. In some of the islands in the Eastern and Pacific Oceans, for the sake of sailing swiftly, boats are used so extremely narrow and sharp, that to counteraet the overturning tendency of their large sails, they have an *outrigger* or projeeting plank to windward, on the extremity of whieh one or more of the crew may sit as a balance.

301. No instance of the lever, with the prop between the forces, is more interesting than the *weighing-beam* or balanee: whether with equal arms, forming the eommon *scale-beam*, or with unequal arms, forming the *steelyard.*

302. We have seen why quantities of matter attached at equal distances from the prop, must be equal to each other in order to balanee. A lever, therefore, whieh enables us to plaee quantities thus exactly in opposition to eaeh other, and which turns easily on its axis, becomes a weighing-beam. Of this the annexed figure shows a common form. The axis or pivot at *c* is sharpened below,

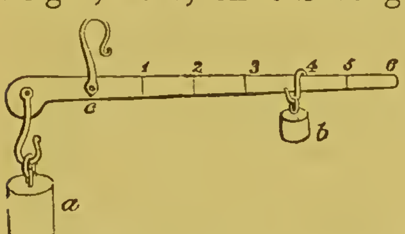


wedgelike, that the beam may turn easily, and that its centre of motion may be nicely determined;—in a delieate balanee for philosophieal purposes, the axis is almost as sharp as a knife edge, and rests on some hard smooth surfaee of support, so as to turn with the weight of a small part of a grain. The scales also of a weighing-beam are suspended on sharp edges, to faeilitate motion, and to determine nicely the points of suspension. If the two arms of a beam be not of exaetly equal length, a smaller weight at the end of the longer will balanee a greater weight at the end of the shorter. An excess of a tenth or other proportion in the length of a beam-arm, to which merchandize is attached, would eheat the buyer of exactly that proportion of his purchase. This case may be detected instantly, by changing the plaees of the two things balaneed; for so, the lighter would be at the short arm, and would then appear doubly light. A beam intended for delicate purposes, and required, therefore, to turn easily, must have its centre of gravity

very near the axis on which the beam turns; for if otherwise, the beam will be in the predicament of a ship with the ballast either too high or too low: in the former case, when once inclined, it would fall over, and could not recover itself; in the latter, it would tend too strongly to remain horizontal, and therefore would be less free to move. The proper situation of the centre of gravity is a little below the axis or line of support, that the beam may return with sufficient readiness from any state of inclination to its horizontal position of rest.

303. It is possible but troublesome to weigh very accurately even with a weighing-beam which is not itself accurately made, provided it has very free motion—first, very nicely to balance in one scale the substance to be weighed, by sand or other matter put into the other, and then to remove the substance, and to put weights into the same scale, until a perfect balance is again produced. Such weights will be the exact equivalent or weight of the substance, however unequal the arms of the balance may be. A projecting rod or plank or branch of a tree, may thus be made to answer the purpose of a weighing-beam, by first attaching the substance to be weighed to its extremity, and observing minutely how far it bends, and then trying what weights will bend it as much.

304. The *steelyard* is a lever with unequal arms, and any weight, as *b*, on the long arm, will balance as much more weight, as *a*, on the short arm, as the former is hanging farther from the fulcrum than the latter. Thus, if the hook at the short end be one inch from the centre of support *c*, a pound weight *b*, on the long arm at four inches, will balance four pounds, *a*, at the short arm. This supposes, however, that the steelyard when bare hangs horizontally, from having a greater mass of matter on the short arm to counterbalance the long slender arm from which the shifting weight hangs. When this is not the case, a corresponding allowance has to be made.

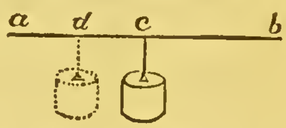


The Chinese, who are so remarkable for the simplicity to which they have reduced all their common implements, weigh any small objects by a delicate pocket steelyard. It is a rod of wood or ivory, about six inches long, with a silk cord passing through it at a particular part, to serve as a fulcrum, and with a sliding weight on the long arm, and a small scale attached to the short one.

The following are examples of levers with both forces on the same side of the prop or fulcrum, and where the more distant force acts as the power.

305. A common wheelbarrow is a lever, in using which a man bears as much less than the whole weight of the load, as the centre of gravity of the load is nearer to the axle of the wheel than to his hands.

306. When two porters carry on a pole a load placed midway between them, they share it equally, that is to say, each bears a half, for the pole becomes a lever, of which each porter is a fulcrum, as regards the other; but if the load be nearer to one end than to the other, he to whom it is nearest bears proportionally more of its weight. A load at *c* is equally borne by a porter at *a* and by one at *b*; but a load at *d* gives three-quarters of its weight to the man at *a*, and only one-quarter to him at *b*.



307. Two horses drawing a plough, act from the ends of a cross bar, of which the middle usually is hooked to the plough. The horses must thus pull equally, to keep the bar directly across. When on heavy land, three horses are yoked, and two of them are made to draw from one end of the bar, it must be attached to the plough by a hook, not at its middle, but half as far from one end of it as from the other.

The oar of a boat is a lever of this kind, where singularly the purpose of fulcrum is served by the unstable water.

The common nut-crackers furnish another instance, by the lever-power of which a person can break a shell many times stronger than he could break with the bare fingers.

308. The consideration of this kind of lever explains, why a finger caught near the hinge of a shutting door is so severely crushed. The momentum of the door acts by a comparatively long lever, upon a feeble resistance placed very near the fulcrum.

The phenomenon of the branch of a tree giving way, when in autumn overloaded with fruit, or in winter with snow, also exhibits the action of this kind of lever. The resistance is the cohesion of the upper side of the branch, and the fulcrum is the part below which is last broken.

The following are examples of the lever, where the two forces are on the same side of the pivot, but where that

nearest to the pivot acts as the power. In this kind, the power is more intense than the resistance.

309. The hand of a man who pushes open a gate while standing near the hinges, moves through much less space than the end of the gate, and hence must act with great force.

When a man uses the common fire-tongs, the ends move much farther than his fingers, and therefore with less strength. No one fears a pinch thus given with the ends of the fire-tongs.

310. Beautiful instances of this modification of lever are exhibited in the limbs of animals. In these the distant extremities, as the hand or foot, required to have great range and freedom of motion, without clumsiness of the limb, and the object has been attained most perfectly by the tendons or ropes which move the limbs being attached near to the joints, which constitute the pivots or fulcra of the bone-levers.

In the human arm, the deltoid muscle, which forms the cushion of the shoulder, by contracting its fibres less than an inch, can raise the hand a yard or more; and of course, if it overcome a force of many pounds placed there, it must itself be acting with a force very intense.—What extraordinary strength of muscle, then, is displayed by one man who lifts another at the end of an extended arm.

How powerful, again, must be the wing-muscles of birds, which, by this kind of action, sustain themselves in the sky for many hours together. The great albatross, with wings extended fourteen feet, is seen in the stormy solitudes of the Southern Ocean, accompanying ships for whole days, without ever resting on the water.

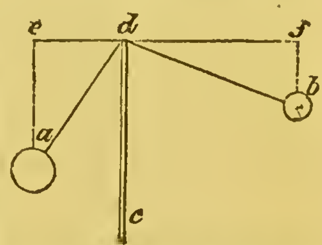
A contraction of about one inch of the glutæi muscles of the hip gives to the human step a length of four feet.

311. While the erroneous opinion prevailed, that machines *increase* power, instead of, as they do, merely *accommodating* forces to purposes, this last kind of lever, where a great force acting through a short distance is made to give great extent of motion and other benefits, was viewed by many as an unprofitable contrivance, and was called the *losing lever*.

312. It is almost unnecessary to say, that the same rule of comparative velocities ascertains the relations required between power and resistance, where a combination of levers is used, as where there is only one. If a lever which makes *one* balance *four*, be applied to work a second lever which does the same,

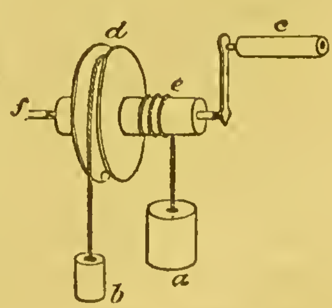
one pound at the long arm of the first will balance *sixteen* pounds at the short arm of the second, and would balance *sixty-four* at the short arm of a third such, &c.

313. The general rule for the lever, that a force may be less intense the farther it is from the pivot, supposes always that the force acts at right angles, or directly across the lever; for if there be any obliquity, there is a corresponding diminution of effect, as explained under the head of *resolution of forces*, at page 58. For instance, one pound at *b* on the end of the long arm of the bent lever *b d a*, because its weight does not act directly across *b d*, has influence only as if it were acting directly at the end of a shorter horizontal arm *d f*; and the two-pound weight at *a* acts only as if it were on a horizontal arm at *e*; now *e* being only half as far from the centre as *f*, two pounds at *a*, in the position of the lever here shown, would just balance the one pound at *b*. In every case, the exact influence of weights is known by referring them to places directly above or below them, on a supposed horizontal lever *e f*. What is called a *bent-lever balance*, is made on the principle here explained. It has on one side a heavy weight as at *a*, and on the other side a scale attached at *b*; and the weight of anything put into the scale is indicated by the position then assumed by the lever, marked by the point at which it cuts an arc of divisions placed behind it. In any common weigh-beam, the point of suspension of the scales being a little below the axis of motion of the beam, there is a degree of the property of the bent-lever balance, and enough to require notice in very nice experiments.

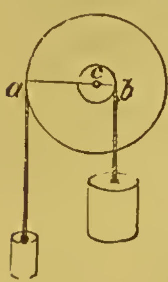


314. "*The Wheel and Axle*"

is the next to be mentioned of the *simple machines*. The letter *d* here marks a wheel, and *e* an axle affixed to it; and we see that in turning together, the wheel would take up or throw off as much more rope than the axle, as its circumference or diameter were greater than that of the axle. If the proportions were as four to one, one pound at *b*, hanging from the circumference of the wheel, would balance four

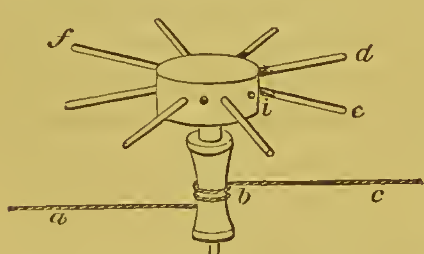


pounds at *a*, hanging from the opposite side of the axle. The proportions are equally indicated, and are usually expressed by comparison of the diameters of the wheel and the axle. Instead of the wheel *d* here shown, the handle or winch *c* may be substituted as explained in 317.



This figure represents the same object as the last, viewed endways. It explains why the wheel with its axle has been called a perpetual lever; for the two weights hanging in opposition, on the wheel at *a*, and on the axle at *b*, are always as if they were connected by a horizontal lever at *a c b*, of which the arms are respectively the diameters of the wheel and the axle, turning on the centre *c* as the prop; and while a simple lever could only lift through a small space, it is evident that this construction will lift as long as there is rope to be wound up.

315. A common crane for raising weights, consists of an axle to wind up or receive the rope which lifts the weight, and of a winch or a large wheel, at the circumference of which the power is applied. That power may be animal effort exerted on the rim or outside of the wheel, or the weight of a man or beast walking within it, and moving it as a squirrel moves the cylinder of his cage.

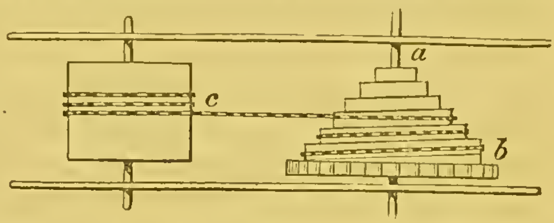


316. The *capstan* used on board of ships, is merely a large upright axle or spindle *b*, which by turning pulls the cable or rope *a b c;* and it is moved by the men pushing at the capstan-bars *d, e, f,* &c., which for the time are stuck into holes made for them in the broader part or drum of the capstan, usually appearing above the deck, at the top of the spindle. These bars may be considered as the spokes of a large wheel, and the effect produced by a man working at one of them is in proportion to his distance from the centre. The capstan is chiefly used on board ships for lifting the anchor, and for doing any other very heavy work. It is applied also to various purposes on shore.

317. The common *winch* (represented as attached to the wheel and axle in 314, at the letter *c*), with which a grindstone is turned, or a crane worked, or a watch wound up, is really in principle a wheel: for the hand of the worker describes a circle,

and there is no difference in the result whether an entire wheel be turning with the hand or only a single bent spoke of a wheel.

318. That part of a common watch called the *fusee* is a beautiful illustration of the principle of the wheel and axle now under consideration. The spring of a watch, immediately after winding up, being more strained, is acting more powerfully to drive on the wheels than afterwards when slacker, and if there were no means of equalizing its action, it would destroy the wished-for uniformity in the motion of the time-piece. The fusee is this means. It may be considered as a barrel or spindle, gradually diminishing from its large end *b*, to its small end *a*, with the surface cut into a spiral groove to receive the chain, by pulling at

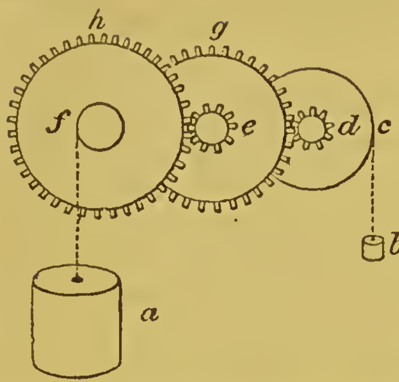


which the spring in the box *c* moves the watch. Now when the watch has been wound up, by a key applied on the axis of the fusee near *a*, the fusee is covered with the chain up to the small end, and the newly bent and strong spring begins to pull by this small end or short lever; and afterwards, exactly as the spring becomes relaxed and weaker, it is pulling at a larger and larger part of the fusee-barrel, and so keeps up an equal effect on the general movement.

319. A large fusee in place of a common cylindrical axle, is often used with a winch, for drawing water by bucket and rope from very deep wells. When the bucket is near the bottom of the well, and the labourer has to overcome the weight of the long rope, in addition to that of the bucket and water, he does so more easily by beginning to wind the rope on a small axle, that is to say, on the small end of the fusee; and in proportion as the length of rope diminishes, he lifts by a larger axle.

320. By means of a wheel, which is very large in proportion to its axle, forces of very different intensities may be balanced, but the machine becomes of inconvenient proportions. It is found preferable, therefore, when such an end is desired, to use a combination of wheels of moderate size. In the adjoining figure three wheels are seen thus connected. Teeth on the axle *d*, of the first wheel *c*, acting on six times the number of teeth in the circumference of the second wheel *g*, turn it only once for every six times that *c* turns; and in the same manner the

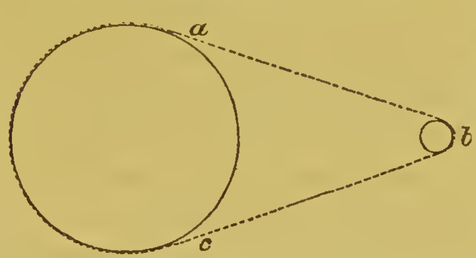
second wheel, by turning six times, turns the third wheel *h* once; the first wheel, therefore, turns thirty-six times for one turn of the last; and as the diameter of the wheel *c*, to which the power is applied, is three times as great as that of the axle *f*, which bears the resistance: three times thirty-six, or 108, is the difference of velocity, and therefore of intensity, between weights or forces that will balance here. — An axle with teeth upon it, as *d* or *e*, is called a pinion.



On the principle of combined wheels, *cranes* are made, by which one man, by working long, can lift many tons. It is even possible to make an engine, by means of which a little wind-mill, of a few inches in diameter, should eventually tear up a strong oak by the roots.

321. The most familiar instances of wheel-work are in our clocks and watches. A few turns of the axle on which the watch-key is fixed, are rendered equivalent, by the train of wheels, to more than ninety thousand beats of the balance-wheel; and thus the exertion during a few seconds, of the hand which winds up, gives steady motion for more than twenty-four hours. By increasing the number of wheels, a time-piece might be made to go for many years.

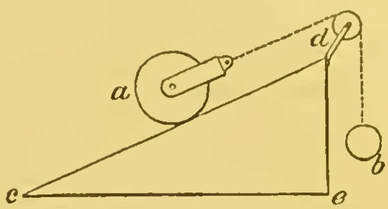
322. Wheels may be connected by bands as well as by teeth. This is seen in the common spinning-wheel, turning lathes, grind-stones, &c. &c. A spinning-wheel, as *a c*, of twenty inches in diameter, turns by its band a bobbin or spindle of half an inch diameter, *b*, forty times for every turn of itself.



323. "*The inclined plane*"

is the third means, which we shall describe of balancing, by solid media, forces of different intensities.—A force pushing a weight from *c* to *d*, only raises it through the perpendicular height *e d*, by acting along the whole length of the plane *c d*; and if the plane be twice as long as it is high, one pound at *b*, acting

over the pulley *d*, would balance two pounds at *a*, or anywhere on the plane: and so of all other quantities and proportions, as already explained under the head of "Resolution of forces," at page 59.



324. A horse drawing on a road where there is a rise of one foot in twenty, is thus really lifting one-twentieth of the load, as well as overcoming the friction and other resistance of the carriage. Hence the importance of making roads as level as possible; and hence our forefathers often erred in carrying their roads directly over hills, for the sake of straightness considered vertically, where by going round the bases of the hills they would scarcely have had greater distance, and would have avoided all rising and falling. Hence, also, a road up a very steep hill is usually made to wind or zig-zag all the way; the ease to the horses being greater exactly as the road is made longer. This rule of road-making is exhibited remarkably in various parts of the world, where hills with almost perpendicular faces have had very safe and commodious roads constructed upon them, leading to forts or residences near their summits. Persons who have visited St. Helena or Gibraltar, or have crossed any high mountain pass, will recollect examples. An intelligent driver, in ascending a steep hill on which there is a broad road, often winds from side to side.

325. The railways of modern times offer a beautiful illustration of this subject. They are made in general so nearly level that in many places the steam-engine which draws the trains has little more to overcome than the friction of the carriages and the resistance of the air.

326. A hogshead of merchandize, which ten men could not lift directly, is often seen rolled into or out of a waggon, by one or two men, who have the assistance of two connected beams forming an inclined plane. There are some canals where, in particular situations, it is found convenient to have the loaded boats drawn up by machinery on inclined planes, instead of being raised by water in locks, as elsewhere.

It is supposed that the ancient Egyptians must have used the inclined plane, to enable them to elevate and place the immense masses of stone, which still remain marvellous specimens of gigantic architecture.

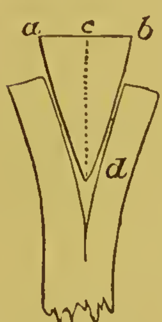
327. Our common stairs are inclined planes in principle; but

being very steep, they are cut into horizontal and perpendicular surfaces, called steps, that they may afford a firm footing.

328. We may here recall that a body falling freely, in obedience to gravity, descends sixteen feet and a fraction in the first second (Art. 175), and that if made to roll down an inclined plane, it moves just as much less quickly (besides the loss from friction and rotation produced), as the height of the plane is less than the length. On a plane sloping one foot in sixteen of its length, a body would descend only one foot in the first second; but this motion being accelerated soon attains a velocity which in collision would be disastrous.

The descent of a pendulum in its arc is completely explained by the laws of the inclined plane. And the laws of the inclined plane itself depend on those of falling bodies and of the *resolution of forces*, reviewed at Art. 174.

329. "*The wedge*"



is merely an inclined plane forced in between resistances to separate or overcome them, instead of, as in the last case, being stationary, while the resistance is forced along its surface. The same rule as to mechanical advantage has been applied to the wedge as to other simple machines; the force acting on a wedge being considered as moving through its *length* $c\ d$, while the resistance yields to the extent of its breadth $a\ b$. But this rule is far from explaining the extraordinary power of a wedge. During the tremor among the particles of the resisting substance produced by the blow of the driving-hammer, the wedge insinuates itself, and advances more quickly than the above rule anticipates.

The wedge is used for many purposes; as for splitting blocks of stone and wood; for squeezing strongly, as in the oil-press; for lifting great weights, as when a ship in dock may be raised a little by wedges driven under the keel, &c.

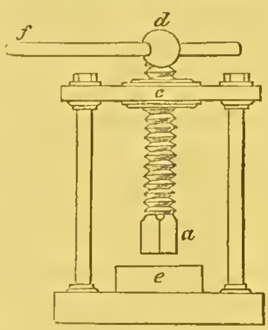
An engineer in London, who had built one very lofty and capacious chimney, to serve for all his steam-engines and furnaces, found after a time that, owing to a defect in the foundation, it was beginning to incline. He then, by driving wedges under one side of it, succeeded in restoring it to perfect perpendicularity.

330. Nails, awls, needles, &c., are examples of the wedge; as

are also all our cutting instruments, knives, razors, the axe, &c. These latter are often used somewhat in the manner of a saw (which is in reality a series of small wedges) by pulling them lengthwise at the same time that they are pressed directly against the object to be cut. The edge of a knife, when viewed through a microscope, is seen to be but a finer saw. It appears that the vibration of the particles produced by the drawing of a knife enables its edge to insinuate itself more easily. The sharpest razor may be pressed directly against the hand with considerable force, and will not enter, but if then drawn along ever so little it starts into the flesh.

331. "*The screw*"

is another of the simple machines. It may be called a winding wedge, for it has the same relation to a straight wedge that a road winding up a hill or tower has to a straight road of the same length and acclivity approaching from a side.



332. A screw may be described as a spindle *a d*, having a thread or worm wound spirally round it, which turns or works in a nut *c*, within which there is a corresponding spiral furrow fitted to receive the thread. The nut is sometimes called the external screw. Every turn of the screw carries it forward in a fixed nut, or draws a moveable nut along upon it, by exactly the distance between two turns of its thread: this distance, therefore, is the space passed through by the resistance, while the force moves in the circumference of the circle described by the handle of the screw, as at *f* in the figure. The disparity between these lengths or spaces is often as a hundred or more to one; hence the prodigious intensity of effect which a screw enables a moderate force to produce.

333. Screws are much used in presses of all kinds: as in those for squeezing oil and juices from such vegetable bodies, as linseed, rapeseed, almonds, apples, grapes, sugar-cane, &c.: they are used also—in the cotton-press, which reduces a great spongy bale, of which few, comparatively, would fill a ship, to a compact or dense package, heavy enough to sink in water;—also, in the common printing-press, which has to force the paper strongly against the broad expanse of type:—a screw is the great agent in our coining machinery,—and in letter-copying ma-

chines:—it is a screw which draws together the iron jaws of a smith's vice, &c. The screw, although producing so much friction as to consume a notable part of the force used in working it, is an exceedingly useful contrivance.

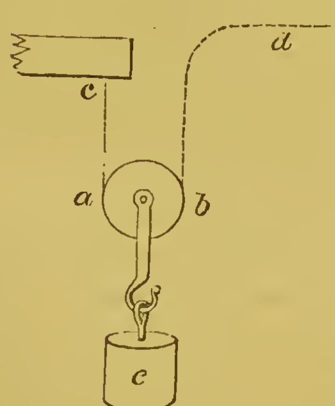
334. As a screw can be made with very numerous turns of its thread in the space of an inch, at perfectly equal distances from each other, it enables the mathematical instrument maker to mark divisions on his work, with a minuteness and accuracy very marvellous. If we suppose such a screw to be pulling forward a plate of metal, or pulling round the rim of a circle, over which a sharp-pointed steel marker can be let down perpendicularly from always the same place, clear lines may be drawn so fine and so close as to be readable only with the aid of a microscope. The instruments called micrometers, by which the sizes of the heavenly bodies and of microscopic objects are ascertained, are worked by fine screws.

335. An *endless screw* is the name given to the combination where a screw acts on teeth surrounding a wheel, so as to produce a continued rotation of the wheel always in the same direction, and the passing of one tooth for every turn of the screw.

A common corkscrew may be regarded as the worm of a screw detached from the central spindle, and it is used, not to produce motion or to connect opposing forces, but merely to pierce and fix itself in the cork.

336. "*The pulley*"

is another *simple machine*, by which forces of different speed and intensity may be balanced.

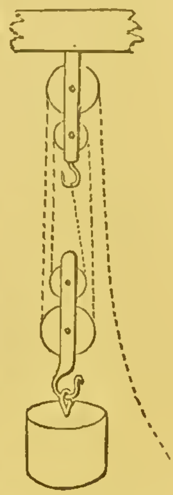


A simple pulley consists of a wheel as *a b*, which has in its grooved circumference the bend of a rope, *c a b d*, and to the axis of which wheel the weight or resistance *e* is attached.

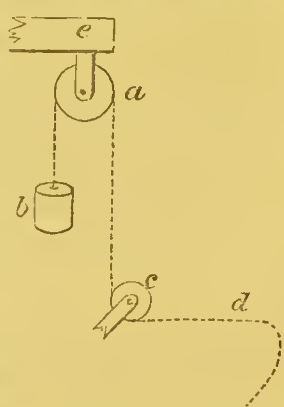
337. In such a construction, it is evident that the weight (let it be supposed one hundred pounds) is equally supported by each ply or length of the rope, and that a man holding up one end, while the other is attached to a fixed support, only bears half of the weight, or fifty pounds; but to raise the weight one foot, he must draw up two feet of rope; therefore, with the pulley he is as if lifting fifty pounds two feet,

where, without the pulley, he would have to lift a hundred pounds one foot.

338. Many wheels may be combined together, and in many ways to form compound pulleys. Wherever there is but one rope running through the whole, as shown here, the relation of power and resistance is known by the number of plies or lengths of the rope supporting the weight, each bearing its due proportion. Here there are four supporting folds, and a power of twenty-five pounds would balance a resistance of one hundred. As persons using pulleys generally find it more convenient to stand upon the ground than to go up and apply their force directly from above to one of the supporting ropes, the last of these is commonly made to pass over a fixed wheel above, and to come down apart from the others, as shown here. This portion not being directly connected with the weight, adds convenience to the pulley, but is not to be counted with the others, in estimating the relation of the power and resistance.



339. In *fixed pulleys*, like those shown at *a* and *c*, there is no mechanical advantage, for the weight just moves as fast as the power; yet such pulleys are of great use in changing the direction of forces. A sailor without moving from the deck of his ship, by means of such a pulley, may hoist the sail or the signal-flag to the top of the loftiest mast. And in the building of lofty edifices, where heavy loads of material are to be sent up every few minutes, a horse, trotting away with the end of the rope from *d*, in a level court-yard, causes the weight or charged basket *b* to ascend to the summit of the building as effectually as if he had the power of climbing, at the same rate, the perpendicular wall.



340. There is a case, however, in which a fixed pulley may seem a balancer of different intensities of force; *viz.* where one end of a rope is attached to a man's body, and the other is carried over a pulley above, and brought down again to his hands, or to a weight of some amount taken to assist him. By using the hands then to pull with force equal to half his weight or less, he supports himself, and may easily raise himself to the

pulley. A man, by a pulley thus employed, may let himself down into a deep well, or from the brow of a cliff, with assurance of being able easily to return, although no one be near to help him; and cases have often occurred where, by such means, a fellow-creature's life might have been saved, or other important object attained. How easily, for instance, might persons either reach or escape from the elevated windows of a house on fire, by such a pulley, conveyed from below or above, where ladders could not be obtained!—This kind of pulley furnishes a convenient means of taking a bath from a ship's stern windows, &c.

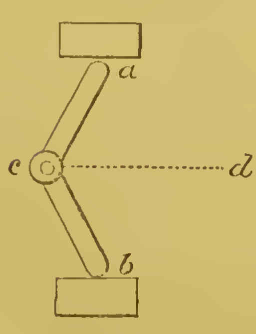
341. The chief use of the pulley is on ship-board. It is there called a block, although strictly speaking, the block is only the wooden frame which surrounds the wheel or wheels of the pulley. It aids so powerfully in overcoming the heavy strains of placing anchors, hoisting the masts and sails, &c., that by means of it, a smaller number of sailors are rendered equal to the duties of the ship. Pulleys are also used on shore, instead of cranes or capstans, for lifting weights, and overcoming other resistances.

Surgeons, in former days, when they trusted rather to mere force than to the address which better information gives, used pulleys, with unnecessary violence, in the reduction of luxations.

The cranks of bell-wires, seen in the corners of our rooms, are bent levers nearly equivalent to fixed pulleys.

342. There is no reason, but old usage, why the appellation of *mechanical power* should have been confined to the six contrivances above explained, as will be seen under the head of "Hydrostatics," when the Hydrostatic press is described.

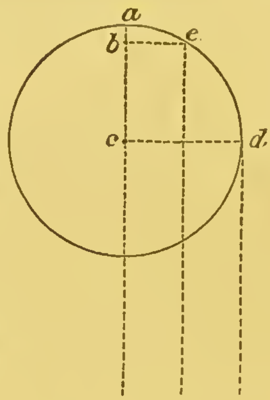
343. *Engine of oblique action,* is a title which includes a variety of contrivances for connecting different velocities.



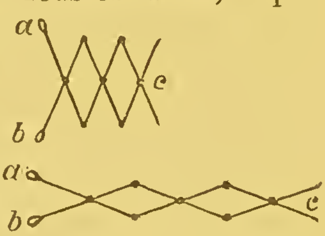
Suppose $c\ a$ and $c\ b$ to represent two strong rods connected together, like a carpenter's folding rule, by a hinge or joint at c. If the distant ends be made to bear against notches in two obstacles, at a and b, and by force then applied to c, the joint c be straightened or carried towards d, the joint c will move through a much greater space than the simultaneous increase of

distance produced between *a* and *b*; and, in proportion to the disparity, the power applied at *c* will overcome a more intense resistance at the extremities *a* and *b*. The mechanical power of this contrivance increases rapidly, the nearer the jointed rods approach to straightness. A convenient form of printing-press applies this principle.

344. The adjoining figure exhibits another mode of connecting an oblique and a direct force, so as to balance them, although of different intensities.—If to turn a wheel (represented here by the circle), a weight be suspended from *d*, it is acting directly, or with its whole force to turn the wheel, for it descends just as fast as the circumference of the wheel moves: but if it were suspended from the point *e*, it would then be acting obliquely to the motion of that part of the wheel, and although moving as fast but not *descending* so fast as if at *d*, it would have as much less effect on the wheel, as the line *e b* is shorter than the line *d c*. The reason of this will be understood by referring to the paragraphs on *resolution of forces* (148), and of *bent levers* (313). This figure explains the varying intensity of the action of a hand on a crank or winch, in different parts of its revolution.



345. The arrangement of cross-jointed rods or wires, represented here, and called the Lazy Tongs, connects different velocities. It has been applied to some curious purposes, but to none of much utility. By pressing the ends *a* and *b* towards each other, the rods, from being in the condensed position represented in the upper figure, immediately assume the outstretched position represented in the lower; so that the end *c* darts forward much farther than the ends *a* and *b* approximate.



346. Different intensities of force are balanced, although not simultaneously, by the following means; which therefore, according to the old notion, have some claim to the name of *mechanic powers*.

347. A man may have a purpose to effect, which a very forcible downward push would accomplish: but his body being

too weak to give that push directly, he may employ a certain time in carrying a weight to such an elevation above his work, that when let fall, its momentum may do what is required. Here the continued effort of the man in lifting the weight, to a height of perhaps thirty feet, may be just sufficient to produce a blow which will drive a stake or pile into the earth one inch; and the proceeding has therefore balanced forces, of which the relation as to intensity is marked by the spaces thirty feet and an inch.

So also *hammers*, *clubs*, *battering-rams*, *slings*, &c., are machines which enable a continued moderate effort to overcome a great but short-lasting resistance.

348. The *fly-wheel*, which by persons ignorant of natural philosophy has often been accounted a positive power, in common cases merely equalizes the effect of an irregular force. In using a winch to turn a mill, for instance, a man does not act with equal force all round the circle; but a heavy wheel fixed on the axle moderates acceleration by receiving or absorbing momentum, while his action is above par, and returns that momentum while his action is below par—thus equalizing the movement. In the common instances of circular motion produced by a crank, as when by the pressure of the foot on a treadle, a lathe or grindstone, or spinning-wheel, is turned, the force is applied during a small part only of the revolution, in the form of interrupted pushes; yet the motion goes on steadily, because the turning grindstone, or wheel, or lathe, becomes a fly and reservoir, equalizing the effect of the force. In a steam-engine which moves machinery by a crank, the upward and downward pushes of the piston are converted, by means of a heavy fly-wheel, into a very steady rotatory motion.

349. A heavy wheel, however, has sometimes been used as a concentrator of force or a mechanic power. By means of a winch, or a weight, or otherwise, motion or momentum being gradually accumulated in the wheel, is then made to expend itself in producing some sudden and proportionally great effect. Thus a man may lift a very heavy weight by first in any way imparting motion to a fly-wheel, and then suddenly hooking a rope from the weight to the axle of the wheel, which rope being wound upon the axle, lifts the weight.

350. A fly-wheel moved in the same manner, and containing the result of a man's action during perhaps one hundred seconds, when made to impel a screw-press, will, with one blow or punch,

convert a piece of smooth metal into a perfect medal or coin; or will, by repeated blows, change a flat plate of silver into a graceful spoon or other utensil.

351. A spring, in the same sense, may become a mechanical power. A person may expend some minutes in bending it, and may then let fly its accumulated energy in an instantaneous blow. A gun-lock shows this phenomenon on a small scale. The slow bending of a bow, which afterwards shoots its arrow with such striking velocity, is another instance.

352. These, then, are the principal means which the solid state of bodies affords us of adapting forces of different intensities to various purposes. We shall find other equivalent arrangements in which fluids co-operate. All of them are of inestimable value to man, by enabling him to accommodate whatever forces he can command to any kind of work which he has to perform. Thus he makes his millstone turn with the same velocity, whether it be moved by the slow exertion of a horse or bullock, walking in a ring, or by the quicker motion of a river gliding under a wheel, or by the rapid gush of a waterfall, or by the invisible swiftness of the wind. And again, each of these forces he can equally apply to turn the heavy millstone or to twist a cotton thread.

353. The wants of men seem first to have led them to use the *simple machines* for the purposes of raising great weights, or overcoming great resistances, and hence the name long used for them of *mechanic powers*—particularly for the Lever, Wheel and Axle, Plane, Wedge, Screw, and Pulley: but the term conveys, as said before, a false idea of their real nature, and has begotten the common prejudice with respect to them that they *generate* force, or have a sort of innate power of performing labour. Now so far is this from being true, that in any case they can only return in a modified form the amount of force derived from some other source diminished considerably by the friction of the moving parts. The truth of this will appear from the following considerations:—

One man may be able, with a tackle of pulleys having ten plies of the rope, to raise a weight which it would require ten men to raise directly without pulleys. But if the weight is to be raised a yard, the ten men will raise it by pulling at a single rope and walking one yard, while the one man with his tackle must walk until he has shortened all the ten plies of rope of one

yard each; that is to say, he must walk ten yards, or ten times as far as the ten men did. In both cases, therefore, to accomplish the same end, there is just the same quantity of man's labour expended, in the first, performed by ten men in one minute, in the second by one man in ten minutes; and if the work were of a nature to continue longer, let us say a whole day for the ten men, it would last ten days for the single man, and there would be ten days' wages of a man to pay in both cases: there is, therefore, no direct saving of human effort from using pulleys; indeed there is some waste of effort, because of the great friction which has to be overcome. Now exactly the like is true of all other simple machines, or mechanic powers; none of them save labour, in a strict sense of the phrase; they only allow a small force to take its time to produce any requisite magnitude of effect, at the expense of additionally overcoming a certain amount of friction, or other such resistance.

354. The real advantages of various machines are such as the following:—

That one man's effort, or any small power, which is always at command, by working proportionally longer, will answer the purpose of the sudden effort of many men, even of hundreds, whom it might be inconvenient and expensive, or even impossible, to bring together.

A ship's company of a few individuals easily weighs the heavy anchor by means of the capstan.

A solitary workman, with his screw-press or other engine, can hold a sheet of paper against types so strongly as to take off a clear impression; to do which without the press no direct effort of the hands of fifty men would suffice; and the many hands would be idle and superfluous except just at the instants of pressing, which occur only at considerable intervals. In this way the screw and one man may be said to do the work of many men.

A man with a crowbar may move a great log of wood to a convenient place, where twenty men would be required to move it without the crowbar; and although the single man then takes perhaps twenty minutes to do what the many men would do in one minute, as the twenty might not be wanted again for the rest of the day, the one man and his crowbar may really be as useful as many men.

It is so important to have correct notions on the subject of the simple machines or mechanical powers, that more space has been here allotted to the explanation of the general principle

than has been usual in such works. After the examination which it has now undergone, however, the author hopes that none of his readers will have difficulty in conceiving clearly that "whatever through a machine, is gained in power, has to be paid for in speed or in time, and *vice versâ*"—or will have difficulty in detecting immediately any common fallacy connected with the subject—as that of supposing, for instance, that a lever, or great pendulum, or spring, or heavy fly-wheel, &c., can ever exert more force than has been passed into it from some source of motion.

355. "*By solid connecting parts, also, the direction of any existing motion or force may be changed. Hence the endless variety of Complex Machines.*" (Read the Analysis at page 85.)

356. It is this power of changing the direction of motion, added to the power of connecting and adjusting various intensities of force and resistance by the simple machines last described, which has enabled man to make complex machines, rivalling in their performances the nicest work of human hands. It would be endless to attempt the enumeration of the modes in which the direction of motions may thus be changed, for it would be to enumerate and describe the whole apparatus of the arts and sciences; but we shall advert to a few as specimens.

357. *Straight motion changed into rotatory.*—The straight motion of wind or water becomes rotatory in wind or water-wheels. The straight-downward pressure of the human foot, acting at intervals on a treadle and crank, turns round the grindstone, and turner's lathe, and spinning-wheel. The alternate rising and falling of the piston of a steam-engine is made, by means of a crank, to turn the great fly-wheel, and thereafter all the other wheels which a steam-engine can move.

Rotatory motion into straight.—An axle in turning will wind up a rope, and thereby lift a weight in a straight line.—A crank on a turning axle, if connected with a pump-rod, will work the piston up and down, or it will work a saw.—Pallets or teeth on a turning-wheel may act on the handle of a great forge-hammer, so that every one in passing shall lift the hammer and produce a blow.

358. We need not multiply instances. By a visit to great manufacturing towns, or, indeed, by simply directing attention to what is passing around, in any part of the civilized world, we

discover miracles of mechanic art:—machines driven by wind, water, or steam for grinding corn;—similar machines for sawing wood and giving it various forms;—others in which rods of metal are seized between rollers, and are flattened into thin plates, as quickly almost as if they were of clay;—spinning machines, which perform their delicate office even more uniformly and perfectly than human hands;—corresponding weaving machines, called power-looms, which work with wondrous speed and steadiness;—paper-making engines, which convert worn-out and apparently useless rags into the uniform and beautiful texture of paper, a texture which, with the farther assistance of types, the engraved plate, and the printing-press, acts as a magic conservatory of the works of mind;—coining machinery;—cranes,—pile-engines,—time-pieces,—all the modern implements of agriculture, of mining, of navigation, &c. &c. If Aristotle deemed the title or definition of *tool-using animal* appropriate to man two thousand years ago, when not one of the things above enumerated was yet in existence, still more strikingly applicable is that title in the present day.

"*Friction.*" (Read the Analysis, page 85.)

359. In estimating the effects of mechanical contrivances, by the rule of the comparative velocities of the power and resistance, there is an important deduction to be made, on account of the friction between the moving parts. In some forms of the steam-engine, where the rubbing parts are numerous, the loss of power from friction may amount to one-third of the whole.

Impediment from friction seems to be owing to a degree of cohesive attraction between the touching substances, and to the roughness of their surfaces, even where, to the naked eye, they appear smooth.

360. It is supposed to be, because the roughnesses, or little projections and cavities, in two pieces of the same substance mutually fit each other, as the teeth of similar saws would, so as to allow the bodies in a degree to enter into each other, that the friction is greater between such, than between pieces of different substances having dissimilar grain.

361. The friction of one piece of iron, wood, brick, stone, &c. on another piece of the same substance, has been measured by using the second piece as an inclined plane, and then gradually

lifting one end of it until the upper mass begins to slide,—the inclination of the plane, just before the sliding commences, is called the angle of repose. This angle, different for different substances, is found to be, for metals, generally such as to mark that the force required to overcome the friction between small pieces of them is equal to about a fourth of the weight of the moving piece; for woods it is about a half. But for large pieces or great pressures, the friction is proportionately much less.

362. It is this angle in the substances concerned, which determines the degrees of acclivity or slope which becomes permanent in the sides of hills composed of sand, gravel, earth, &c., and in the banks of canals, rivers, water reservoirs, &c.

If the thread of a screw winds round the spindle with an angle less than this, the screw can never recoil or slide back from force acting against its point.

363. But for friction, men walking on the ground or pavement would always be as if walking on ice; and our rivers, that now flow so calmly, would all be rapid torrents. It is friction which retains all loose objects on earth in the situations in which for convenience men choose to place them—the furniture of a house, the contents of libraries, museums, &c. Friction is therefore of the highest utility to men.

364. Friction it is which enables men, out of the comparatively short fibres of cotton, flax, or hemp, to form lengthened threads, cordage, webs, &c.; for friction alone, consequent upon the mutual pressure of the interwoven and twisted fibres and threads, keeps the material of all these fabrics together.

365. The following means are employed to diminish friction where desired between rubbing surfaces, and are used singly or in combination, according to circumstances.

1. Making the rubbing surfaces smooth.

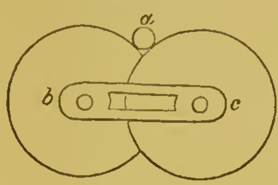
2. Interposing some lubricating substance between the rubbing parts; as oils for the metals, soap, grease, black-lead, &c. for the woods.

3. Letting the substances which are to rub on each other be of different kinds. Axles are made of steel, for instance, and the parts on which they bear are made of gun-metal or brass: in small machines, as time-keepers, the steel axles often play in agate or diamond. The swiftness of a skater depends much on the great dissimilarity between steel and ice.

4. Diminishing the extent of the touching surfaces; as by making the rubbing part of the axis of a wheel small.

5. Using wheels, as in wheel-carriages, instead of dragging a solid mass or sledge along the ground. Castors on household furniture are miniature wheels.

6. Using what are called friction-wheels;—which still farther diminish the friction even of a smooth axis, by allowing it to rest on their circumferences, which turn with it. Here *a* represents the end of an axis, resting on the rims of two friction wheels, *b* and *c*.



7. Placing the thing to be moved on rollers or balls, as when a log of wood is drawn along the ground upon smaller round pieces; or when a heavy cannon, with a flat circular base to its carriage, is turned round by rolling on loose cannon-balls having a hard level bed. In these two eases there is very little friction, the resistance being chiefly from the obstacles which the rollers or balls may have to pass over.

Of all rubbing parts, the joints of animals, considering the strength, frequency, and rapidity of their movements, are those which have the least friction. The rubbing surfaces in these are eovered, first, with a layer of elastic cartilage, and then with an exceedingly smooth membrane, over which there is constantly poured from glands around a fluid called synovia, more emollient and lubricating than any oil, and which is renewed constantly as required. We study and admire the perfection of animal joints, without being able very closely to imitate them.

366. *Wheel carriages* demand notice here, as illustrating many of the eircumstances connected with friction, and as being among the most common and important of machines.

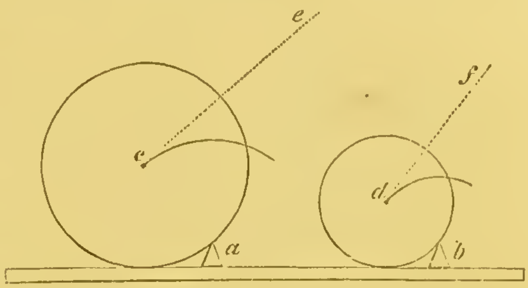
Wheel carriages have three advantages over the ancient sledges for which they are the substitutes:

1. The rubbing or friction, instead of being between an iron shoe and the stones and irregularities of the whole road, is between the axle and its surrounding bush, of which the surfaces are smoothed and fitted to each other, and well lubricated.

2. While the earriage moves forward, ten or fifteen feet, by one revolution of its wheel, the rubbing part, *viz.* the axle, slides over only a few inches of the internal surface of its smooth greased bush.

3. The wheel instead of butting against any abrupt obstacle on the road, as a mass of stone would, surmounts it by the axle describing a gentle curve over it,—as shown in this figure, where

a represents an obstacle, and where the curve from *c*, of which the beginning has the direction shown by the line *c e*, represents the path of the axle in surmounting it. The wheel is as if rising on an inclined plane, and gives to the drawing animal the relief which such a plane would bring. This kind of advantage is greater in a large than in a small wheel, for evidently the smaller wheel here represented, in having to surmount more quickly the same size of obstacle, has to rise in the shorter and steeper curve beginning at *d*. It is true, again, that a small wheel will sink to the bottom of a hole or depression in the road, where a larger one would rest on its edges as a bridge, and would sink less.—The fore-wheels of carriages are usually made small, because such construction, by allowing the wheel to pass under the body of the carriage while turning, facilitates the turning. It is not true, however, according to the popular prejudice, that the large hind-wheels of coaches and waggons help to push on the little wheels before them, as if the carriage were on an inclined plane; but there is the accidental advantage, that in ascending a hill, when the horses have to put forth their strength, the load rests chiefly on the large hind-wheels, and in descending, when an increased resistance is desirable, the load falls chiefly on the smaller fore-wheels.

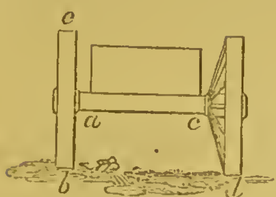


367. From the causes mentioned in the last paragraphs, the difference in performing the same journey of a mile, by a sledge and by a wheel-carriage, is, that while the former has to rub over every roughness in the whole mile of road and to be sharply jolted by every irregularity, the rubbing part of the latter, the axle, glides very slowly over a few yards of a smooth oiled surface, in a gently waving line.

On hilly roads, in descending, it is common to lock or fix one of the wheels, or to place under it a small sledge called a shoe, which, by the friction produced, saves to the horses the labour of holding back.

368. The wheel of a carriage, simple as, from our extreme familiarity with it, it now appears to us, is a thing of very nice workmanship, and which has exercised much ingenuity.—It acquires marvellous strength, somewhat that of the arch, from

what is called its *dished* form, seen here in the wheel *c d*, as contrasted with the flat wheel *a b*. In a wheel of this form, the extremity of a spoke cannot be pressed or strained inwards, or towards the carriage, unless the rim of the wheel be enlarged, and all the other spokes yield at the same time; and it cannot be displaced outwards, or away from the carriage, unless the rim be diminished, or the other spokes yield in the opposite direction:—now the rim being bound by a strong ring, or tire of iron, cannot suffer either increase or diminution, and the strength of all the spokes is thus by it compelled to aid each individually. In a perfectly *flat* wheel a given degree of displacement outwards or inwards of the extremities of any one spoke, is not resisted by the strength of all the others. A watch-glass and a round piece of egg-shell are stronger than flat pieces of like thin substances, for the same reason that a dished wheel is stronger than a flat wheel.



369. The application of springs to carriages, which is an improvement of comparatively recent date, not only renders them soft-moving vehicles on rough roads, but much lessens the pull to the horses. When there is no spring, the whole load must rise with every rising of the road, and if time be given, must sink with every depression, and the depression costs as much labour as the rising, because the wheel must be drawn up again from the bottom of it; but in a spring-carriage moving rapidly along, only the parts below the springs are moved in correspondence with the road-surface, while all above, by the inertia of the matter, have a soft and even advance. Hence arises the superiority of those modern carriages, furnished with what are called *under-springs*, which insulate from the effect of shocks, all the parts, excepting the wheels and axletrees themselves. When only the body of the carriage is on springs, the horses have still to rattle the heavy frame-work below it over all irregularities, and then the wheels, as well as the structure generally, require to be of much greater strength and weight to bear the consequent shocks.

370. It was a happy thought which, a few years ago, led to the extended use for children of the small spring carriage called the perambulator, substituted in many cases for the nurse's arms. By it the fresh air of dry open localities even at considerable distance from the home may be reached with

diminished trouble to the attendants and with a new delight to the children.

The subject of wheel carriages is interesting to medical men, from their having often to direct in transporting the sick and wounded.

371. We have now to remark that even all the improvements previously made in regard to roads and carriages appear of small significance in comparison with what British ingenuity and enterprise have lately achieved through the iron railway, with its locomotive engine or steam-horse. By these, men now travel, and transport heavy loads, at a rate exceeding forty miles an hour, equalling the speed of a bird's flight or of a strong wind! When first proposed, persons unskilled in Natural Philosophy regarded the scheme as an impracticable dream. To aid in removing such general misconception, the author introduced in the first edition of this work, in 1827, the two following paragraphs. And he still retains them as serving to make young readers aware of the astounding changes which, within the intervening time, have been effected by the railroad, in the condition, not of Britain alone, but of the whole civilized world.

372. "Contrasted with the clumsy vehicles and rough roads of times not yet remote, few things seem more perfect than modern wheel carriages and the roads made for them. Yet we are now perhaps on the eve of a farther change, which for many purposes will be of greater importance than all that had yet been achieved—*viz.* the general adoption of railroads with locomotive steam-engines to suit them. To those who study such subjects, it is known, that to drag a loaded waggon up the side of a considerable hill, costs more force than to send it thirty or forty miles along a good level road; and the conclusion is obvious, that although the original expense of forming the level might considerably exceed that of making a road over hills, still, in situations of great traffic, the difference would soon be paid for by the savings, and when once paid, the savings would be as a profit for ever. To readers conversant with political economy, it would be superfluous to speak here of the advantages of facility of intercourse, but to those who as yet are not, the following reflections may be interesting.

"In reviewing the history of the human race, we find that remarkable advances in civilization have taken place generally in proportion to the facilities of intercourse among the people

offered in the particular situations. First, therefore, civilization grew along the banks of great rivers, as the Nile, the Euphrates, and the Ganges; or along the shores of inland seas and archipelagos, as in the Mediterranean and the numerous islands of Greece; or over fertile and extended plains, as in many parts of India. When the situation thus bound a great number of individuals into one body, the useful new thought or action of any gifted individual, which, in the insulated state, would soon have been forgotten and lost, extended its influence immediately to the whole body, and became the thought or action of all who could benefit by it, being recorded too for ever, as part of the growing science or art of the community. Then in a numerous society, such useful thoughts and acts would naturally be more frequent, because persons feeling that they had the eyes of a multitude upon them, and that the rewards of merit would be proportionally great, would be excited to emulation in all the pursuits that could contribute to the well-being of the society. Men soon learned to estimate aright these and many other advantages of easy intercourse, and after having early possessed themselves of the stations naturally fitted for their purposes, they began to improve the old and to make new stations. They created artificial rivers and shores and plains of their own, that is to say, they constructed canals and basins and roads; thereby connecting artificially regions which nature seemed to have separated for ever.—In the British isles, whose favoured children have taken so remarkable a lead in showing what prodigies wise policy may effect, the advantages arising from a few lines of canal and road first executed, soon led to numberless similar enterprises, and within half a century the empire has been thus more closely tied together in all directions: and it seems as if the noble work were now to be crowned by the substitution of level railways for many of the common roads and canals. Short portions of railroad have already been constructed, and although they and the carriages upon them are far from having the perfection which philosophy says they will admit, the results have to the intelligent observer been very satisfactory. If we suppose the progress to continue, and the price of transporting things and persons to be reduced to a fourth of the present charge—and in many cases it may be less; and if we suppose the time of journeying with safety also to be reduced in some considerable degree,—of which there can be as little doubt—the general adoption of such roads

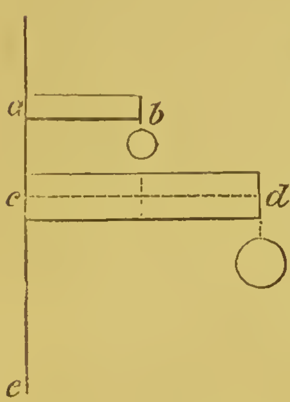
would operate an extraordinary revolution and improvement in the state of society. Without in reality changing the distances of places, it would in effect make all places nearer to each other, giving to every single spot in the kingdom the conveniences of almost all,—of town and country, of sea-coast and of highland district. A man, wherever residing, might consider himself virtually near to any other part, when at the expense of time and money now expended in travelling a short way, he might travel far; and he would thus find remarkably extended the sphere both of his business and of his pleasures. The over-crowded and unhealthy parts of towns would scatter their inhabitants into the country; for the man of business could reach his post as conveniently from a distance of several miles as he now does from an adjoining street. The present heavy charges for bringing distant produce to market being nearly saved, the buyer everywhere would purchase cheaper, and the producer would be still better remunerated. In a word, such a change would be effected as if by magic the whole of the British isles were compressed into a circle of a few miles in diameter, and yet without losing aught of their extent or beauties.—All this must to many appear visionary; but it is less so than seventy years ago it would have been to anticipate much of what, in respect to travelling, has really come to pass,—as, for instance, that the common time of journeying from London to Edinburgh by mail coach would be reduced to forty-six hours. At the recent trial (in 1825) of the railroad near Darlington, a train of loaded carriages was dragged by one little steam-engine a distance of twenty-five miles within two hours; and in some parts of the journey the speed was nearly twenty miles an hour: the load was equal to a regiment of soldiers, and the coal expended was not of the value of a crown. An island with such roads would seem to be an impregnable fortress; for in less time than an enemy would require to disembark on any part of the coast, the forces of the country might be concentrated to defend it." *All here foretold is now more than realized!*

373. "*Strength depends on the magnitude, form, and position of bodies, more than on the degree of cohesion in their material.*" (Read the Analysis, page 86.)

The minute details connected with this branch of the subject belong to the practical engineer, but there are some of the general truths which should be familiar to everybody.

374. *Of similar bodies the largest is proportionally the weakest.*

Suppose two blocks of stone to be left projecting from a hewn rock, or a strong wall, of which blocks one, as *d*, were just twice as long and deep and broad as the other, *b*, and had, therefore, eight times as much substance in it. (See the Appendix.) The larger one would by no means support at its end as much more weight than the smaller, as its mass were greater, and for two reasons. 1st. In the larger, each particle of the surface of attachment at *c*, in helping to bear the weight of the block itself, has to support by its cohesion twice as many particles beyond it in the double extent of projection, from *c* to *d*, as a particle has to support in the shorter block at *a* from *a* to *b*; and 2ndly, both the additional substance, and anything appended at its outer extremity, are acting with a double lever advantage to break the block, that is, to destroy the cohesion at *c*. Hence it follows, that if any such mass be made to project very far, it will be broken off, or will fall by its own weight alone. What is thus true of a block supported at one end is equally true of a block supported at both ends, and indeed of all masses, however supported, and of whatever forms, if they have projecting parts. It is to be observed, farther, that perpendicular masses, like cliffs on the sea shore, which have no projecting or overhanging parts, are still limited as to size by the degree of cohesive force among their particles, for the upper part of such a mass tends to crush or break down the lower. A lofty pillar cannot be formed of soft clay, and a wall of hardest brick would crush the bottom layers to dust before it reached the elevation of a thousand feet.



That a large body, therefore, may have proportionate strength to a smaller, it must be still thicker and more clumsy than it is longer; and beyond a certain limit no proportions whatever will keep it together in opposition merely to the force of its own weight.

This great truth limits the size and modifies the shape of most productions both of nature and of art;—of hills, trees, animals, architectural or mechanical structures, &c.

375. *Hills.*—Very strong or cohesive material may constitute hills of sublime elevation, with broken cliffs and precipices nearly perpendicular; and such accordingly are seen where the hard granite protrudes from the bowels of the earth, as in the Andes of America, the Alps of Europe, and the Himalayas of Asia. But material of inferior strength exhibits more humble risings and more rounded surfaces. The gradation is so striking and constant, from mountains of granite down to those of chalk or gravel or sand, that the geologist can often tell the substance of which a hill is composed merely by observing the peculiarities of its shape.

Even in granite itself there is a limit to height and projection; and if an instance of either, more remarkable than now remains on earth, were by any chance to be produced again, the law which we are considering would prune the monstrosity. The grotesque figures of rocks and mountains seen in the paintings of the Chinese, or actually formed in miniature for their gardens, to express their notions of the picturesque and sublime, are caricatures of nature for which exact originals can never have existed. Some of the islands in the Eastern Ocean, however, and some of the mountains of the chains seen in a voyage towards China, along the coasts of Borneo and Palawan, and Manilla, which the author in passing along had the opportunity of sketching, exhibit the very limits of possibility in singular shapes. In our moon, where the weight or gravity of bodies is less than on earth, because of her smaller size, mountains of a given material might be much higher than on earth; and astronomers have found that the lunar mountains are in fact very high.

By the action of winds, rains, currents, and frost, upon the elevated masses around us, there is unceasingly going on an undermining and wasting of supports, so that every now and then portions are torn by gravity from elevated station to sink to lower levels in obedience to the law now explained.

376. *The size of vegetable growths* is, of course, obedient to the same law. There are no trees reaching a height of three hundred feet, even when perfectly perpendicular, and sheltered in forests that have been unmolested from very remote antiquity: and oblique or horizontal branches are kept within comparatively narrow limits by the great strength required to support them. The truth, that to have proper strength the breadth or diameter of bodies must increase more quickly than

the length, is well illustrated by the contrast existing between the delicate and slender proportions of a young oak or pine yet in the seedsman's nursery, and the sturdy form of one which has braved for centuries all the winds of heaven.

377. *Animals* furnish other interesting illustrations of this law. How massive and clumsy are the limbs of the elephant, the rhinoceros, the heavy ox, compared with the slender forms of the stag, antelope, and greyhound! And unless the bones were made of stronger material than now, an animal much larger than the elephant would be crushed to the earth by its weight alone. The whale is the largest of animals, but feels not its enormous weight, because lying constantly in the liquid support of the ocean. A cat may fall with impunity from a greater height than would suffice to dash the bones of an elephant or ox to pieces.

For the reason which we are now considering, the giants of the heathen mythology could not have existed upon this earth. In the planet Jupiter, which is many times larger than the earth, an ordinary man from hence would be carrying in the simple weight of his body a load several times greater than he bears here. The phrase, *a little compact man*, points to the fact that such a person is stronger in proportion to his size than a taller man.

378. The same law limits the height and breadth of architectural structures. In the houses of fourteen stories, which formerly stood for protection close under the guns of the castle of Edinburgh, there was danger of the superincumbent wall crushing the foundation.

Roofs.—Westminster Hall approaches the limit of width which, if using wood as the material, is attainable without very inconvenient proportions or central supports.

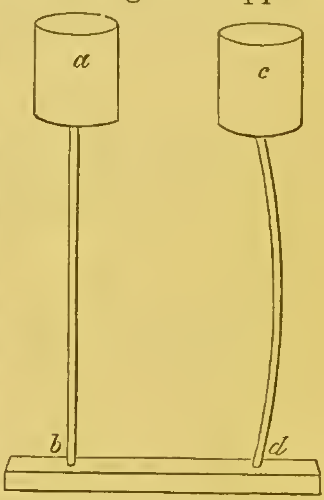
Arches of a bridge.—A stone arch, much larger than those of the magnificent bridges in London, would be in danger of crushing or splintering its material by the horizontal thrust of its mass.

379. *Ships.*—A ship's yard, ninety feet in length, contains twenty times as much wood as a yard of thirty feet, and even then is not so strong in proportion.

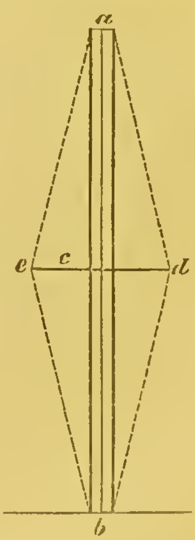
380. Since iron, within the present century, because of its stronger cohesion has been substituted for wood and stone, in the construction of roofs, domes, bridges, ships, &c., vastly greater dimensions are attainable in all.

381. The degree in which the strength of constructions is dependent on the form and disposition of their parts will be illustrated by considering some cases of *longitudinal* and transverse compression. And in these it will appear that the resisting or preserving forces are often allowed only partially to oppose the forces that tend to destroy. If a party of men were contending with another party of whom some had their hands tied, or were fighting among themselves, the combat would be very unequal.

382. In *longitudinal compression*, as produced by a body *a*, on the atoms of the support *b*, the weight, while the support remains straight, can destroy the support only by crushing it in opposition to the repulsion and impenetrability of all of its atoms. Hence a very small pillar, if kept perfectly straight, supports a very great weight; but a pillar originally crooked, or beginning to bend, resists with only part of its strength; for, as seen in *c d*, the whole weight above is supported chiefly on the atoms of the concave side, which are therefore in greater danger of being oppressed and crushed, while those on the convex side, separated from their natural helpmates, are in the opposite danger of being torn asunder. The atoms near the centre in such a case are almost neutral, and might be absent without the strength of the pillar being much lessened.



383. Long pillars or supports are weaker than short pillars of the same diameter, because they are more easily bent; and they are more easily bent because a very inconsiderable, and therefore easily effected yielding between each adjoining two of their many atoms, makes a considerable bend in the whole; while in a very short pillar there cannot be much bending without a great change in the relation of proximate atoms, and such as can be effected only by great force. The weight resting on any pillar, and bending it, may be considered as acting with the mechanical aid of a long lever which reaches from the extremity to the centre of the pillar, against the strength



resisting always directly at a short lever reaching from the side of the pillar to the centre: the strength of the pillar, therefore, has relation to the difference between these levers and to the degree of bending. Shortness then, or any lateral stay or projection, as *a e b*, which, by making the resisting lever longer, opposes bending, really increases the strength of a pillar.

A column with ridges projecting from it, is on this account stronger than one that is perfectly smooth.

384. A hollow tube of metal is stronger than the same quantity of metal as a solid rod, because its substance standing farther from the centre resists bending with a longer lever. Hence pillars of cast iron are generally made hollow, that they may have great rigidity and strength with as little metal as possible.

In some perfect weighing-beams for delicate purposes, that there might be the least possible weight with the required strength, the arms, instead of being of solid metal, are hollow cones, of which the substance is not much thicker than writing-paper.

Masts and yards for ships, and great cranes for raising weights, are now made of iron, and hollow, in accordance with the same principle.

In Nature's works we have to admire numerous illustrations of the same kind.

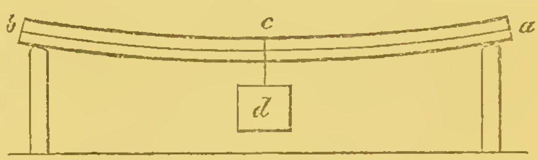
385. The stems of many vegetables, instead of being uniformly round externally, are ribbed or angular and fluted, that they may have strength to resist bending. Many also are hollow, as corn-stalks, the elder, the bamboo of tropical climates, &c., thereby combining lightness with their strength.—A person who has visited the countries where the bamboo grows, cannot but admire the almost endless uses among the inhabitants, which its straightness, lightness, and hollowness fit it to serve. Being found of all sizes, it has merely to be cut into pieces of the lengths required for special purposes, and Nature has already been the turner, and the polisher, and the borer, &c. On many of the shores and islands of Eastern Asia it is the chief material, both of the dwellings, and of the furniture; there are the bamboo huts and bungalows, containing their bamboo chairs, couches, beds, &c.; flutes and other musical instruments there, are merely pieces of the reed with holes bored at the requisite distances; conduits for water are pipes of bamboo; bottles and

casks for preserving liquids are single joints of larger bamboo with the natural partitions remaining; and bamboo split into threads is twisted into rope, &c.

386. From the animal kingdom also we have numerous illustrations of our present subject:—as in the hollow stiffness of the quills of birds; the hollow bones of birds; the bones of animals generally, which are strong and hard, and often angular externally, with light cellular texture within, &c.

Transverse Pressure.

387. When a horizontal beam is supported at its extremities, as at *a* and *b*, its weight bends its middle down more or less, as here shown, the particles on the upper side being compressed, while the parts below are distended; and the bending and tendency to break are greater, according as the beam is longer and its thickness or depth is less.



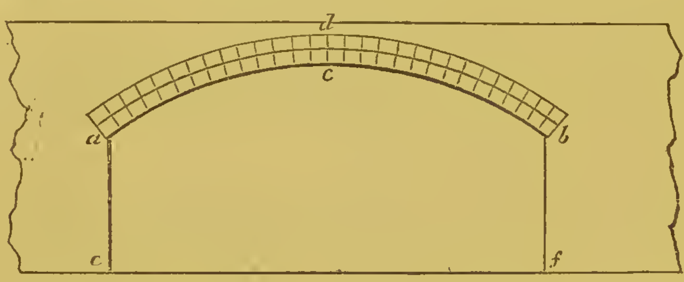
388. The danger of breaking, in a beam so situated, is judged of, by considering the destroying force as acting by a long lever reaching from an end of the beam to the centre, and the resisting force or strength as acting only by a short lever from the side *d* to the centre; while only a small part of the substance of the beam on the under side is resisting strongly. This last circumstance is so remarkable, that the scratch of a nail on the under side of a plank resting as here supposed, will sometimes suffice to begin the fracture.

389. Because the resisting lever is small in proportion as the beam is thinner, a plank bends and breaks more readily than a beam, and a beam resting on its side bears less weight than if resting on its narrower edge. Where a single beam cannot be found deep or broad enough to have the strength required in any particular case, as in supporting the roof of a house, several beams are joined together, and in a great variety of ways, as is seen in house-rafters, &c. which, although consisting of three or more pieces, may be considered as one very broad beam, having those parts cut out which would contribute least to the strength.

390. Within a few years, in place of the great wooden beams formerly employed where heavy burdens had to be borne, iron beams called girders are now substituted. There is scarcely a limit to the size and strength which these may be made to

possess, by giving the tubular or hollow form in many cases, and letting the material be thicker where the strains are greater. Even the Britannia Bridge, stretching across an arm of the sea from Wales to Anglesea, is, in its central part, only a square-cornered tube, 600 feet long (once and a half times as long as St. Paul's Cathedral is high), supported only at its extremities, but so strong, that railway trains pass through at a full speed with perfect security.

391. *The arched form*, resting against immoveable abutments, bears transverse pressure so admirably as it does, because by means of it the force that would destroy, is made to compress, not one side only of the mass, but all parts of both sides, nearly in the same degree. By comparing this figure with the last, we see that the atoms on the under side of an arch, must be compressed as much as those on the upper side, and are therefore in no danger of being torn, or overcome separately.



The whole substance of the arch therefore resists, nearly like that of a straight vertical pillar under a weight, and is nearly as strong.

392. An error, which has been frequently committed by bridge-builders, is the neglecting to consider sufficiently the effect of the horizontal thrust of the arch on its piers. Each arch is an engine of oblique force (see Art. 343), pushing the pier away from it. In some instances, one arch of a bridge falling, has allowed the adjoining piers to be pushed down towards it, by the thrust, no longer balanced, of the arches beyond, and the whole structure has given way at once like a child's house or bridge built of cards.

It is not known at what time the arch was invented, but it became common in comparatively modern times. The hint may have been taken from nature, for there are instances in alpine countries of natural arches, where rocks have fallen between rocks, and have there been arrested and suspended, or where burrowing water has at last formed a wide passage under masses of rock, leaving them balanced among themselves as an arch above the stream. Nothing can surpass the strength and beauty

of some modern stone bridges;—those, for instance, which span the Thames as it winds through London.

393. Arched bridges of iron have been made with spans twice as wide as those of stone: the material being more tenacious and easily moulded, is calculated to form a lighter whole. The bridge of three such arches built in 1819, between the City of London and Southwark, is a noble specimen; and compared with those erected in the preceding century, appears almost a fairy structure of lightness and grace.

394. Great domes, as of churches, &c., have strength nearly on the same principle as simple arches. They require to be strongly bound at the bottom with iron bars, or otherwise, to counteract the horizontal thrust of the superstructure.

The Gothic arch is a pointed arch, and is calculated to bear the chief weight near its summit or key-stone. Its use, therefore, is not properly to span rivers as a bridge, but to enter into the composition of ornamental architecture. With what effect it does this, is seen in the truly sublime Gothic structures which adorn so many parts of Europe.

395. The following are instances, in smaller bodies, of strength obtained by the arched form.—A thin watch-glass bears a very hard push;—a dished or arched wheel for a carriage is many times stronger to resist all kinds of shocks than a perfectly flat wheel;—a full cask may fall with impunity, where a strong square box would be dashed to pieces;—a very thin globular flask of glass, corked and sent down many fathoms into the sea, will resist the pressure of water around it, where a square bottle, with sides of much greater thickness, would be crushed to pieces.

396. We have, from the animal frame, an illustration of the arched form giving strength, in the cranium or skull, and particularly in the skull of man, which is the largest in proportion to its thickness:—the brain required the most perfect security, and in the arched form of the skull has this without much weight.—The common egg-shell is another example of the same class: what hard blows of the spoon or knife are often required to penetrate this wonderful defence of a dormant life! The weakness of a similar substance not arched, is seen in a scale from a piece of freestone which so readily crumbles between the fingers.

To determine, for particular cases, the best forms and positions of beams and joists, of arches, domes, and so forth, is the business of strict calculation, and belongs therefore to practical architecture or engineering.

It was a beautiful problem of this kind, which Mr. Smeaton, the English engineer, a century ago, solved so perfectly, in the construction of the far-famed Eddystone lighthouse. He had to determine the form and arrangements of a building, which should stand firm on a sunken rock, from where preceding structures had been swept away, in the channel of a swift ocean tide, and exposed to the fury of tempests from every quarter. The man who has himself been driven before the irresistible storm in the darkness of night, and in the midst of dangers, and whose eyes have watched the steady ray from the lighthouse which saved him, has been led fully to appreciate the importance of the knowledge which leads to such precious results, and can judge how wise it would be in governments to promote the study of the natural sciences as part of general education. An engineer who succcssfully executes such works not only obtains honour and other reward for himself, but is accomplishing philanthropic ends, which tend to bind the whole of humankind into one great society of helping brotherhood.

ANIMAL MECHANICS.

Mechanism of the Human Skeleton.

HAVING now reviewed the doctrines of general mechanics, we proceed, with the light thence derived, to consider the solid framework of the human body, a perfect structure which Divine Wisdom has willed into existence to serve the purposes of life and happiness to man.

397. There is scarcely a part of the animal body, or an action which it performs, or an accident that can befal it, or a piece of professional assistance which can be given to it, that has not close relation to the truths of natural philosophy here set forth. It follows that every individual who has such a complex and delicate body to care for, should understand its nature to a certain degree; and that those who embrace the profession of which the object is to guard the public health, and to cure or mitigate evils which befal, should have that knowledge as complete as is attainable. Three centuries have not yet passed since the now renowned Dr. Harvey, because he had studied mechanical philosophy more fully than his professional brethren generally, made the most important discovery in regard to the nature of living beings which anywhere had yet been made, namely, that of the never-ceasing circulation of the blood in every part of the animal body.

398. The *cranium* or *skull** has been already mentioned as an instance of the arched form answering the purpose of giving strength. The brain, in its nature, is so delicate or susceptible of injury, that slight local pressure disturbs its action. Hence a solid covering like the skull was required, with those parts of it made stronger and thicker which are most exposed to injury. An architectural dome is constructed to resist one kind of force only, always acting in one direction, namely gravity, and therefore its strength increases regularly towards the bottom, where the weight and horizontal thrust of the whole are to be resisted;

* An engraving of the skeleton such as is now used in common schools is given at the end of the volume.

but in the skull, as in a barrel or egg-shell, the mere tenacity of the substance is many times greater than sufficient to resist gravity, and therefore the peculiar form and securities are calculated to resist forces of other kinds operating in all directions. When we reflect on the strength displayed by the arched film of an egg-shell, we need not wonder at the severity of pressure and even of blows which the cranium can withstand.

In the early fœtal state, that which afterwards becomes the strong bony case of the brain exists only as a tough flexible membrane. Ossification commences in this membrane long before birth, at a certain number of points from which it spreads, and the portions of the skull formed around these points soon acquire the appearance of so many scales or shells applied on the surface of the brain, and held together by the remaining membrane not yet ossified. These afterwards become firmly fixed together, by projections of bone from the edges of each, shooting in among similar projections of the adjoining ones, until all mutually cohere by perfect dove-tailed joints, as does the work of a carpenter. These joints are called the sutures of the cranium, and are visible to extreme old age. Through early childhood, the cranium remains to a certain degree yielding and elastic, causing the falls and blows, so frequent during the lessons of walking, &c., to be borne with comparative impunity.

A very severe blow on a narrow part of the skull generally fractures and depresses the part, as the blow of a hammer; while one less severe, but with more extended contact, being stoutly resisted by the arched form, often injures the skull by what corresponds to the *horizontal thrust* in a bridge, causing a crack at a distance from the place struck, generally half-way round to the opposite side.

399. *In the lower jaw* we have to remark the greater mechanical advantage, or lever-power, with which the muscles act, than in other parts of animals. The temporal muscles pull almost *directly* across, or at right angles to the line of the jaw, while in most other cases, as in that of the muscles about the shoulder joint lifting the arm, the muscles act very *obliquely*, and with power diminished in proportion to the obliquity. Even the human jaw can crush a very resisting body; and the jaws of the lion, tiger, shark, or crocodile, have power which surprises.

400. The *teeth* rank high among those parts of the animal body which appear almost as if they were the results of distinct miraculous agencies constantly renewed, so difficult is it to

suppose simple laws of life capable of producing the variety of form and fitness, constantly changing with age, which they exhibit. They constitute a beautiful set of chisels and wedges, so arranged as to be most efficient for cutting and tearing and grinding the food, with an exterior enamel so hard and chemically incorruptible, that few substances in nature can make an impression upon it. In early states of human society, teeth were used for many purposes for which steel is used now. It seems, however, as if the laws of life, marvellous to human intellect as they are, had still been inadequate to cause teeth cased in their hard polished enamel to expand or grow as the softer bones grow; and hence has arisen a provision more extraordinary still. A set of small teeth come soon after birth, and serve the child until six or seven years of age: these then fall out, and are replaced by larger ones, which endure for life; the number of the latter, being completed only when the man or woman is full grown by the four teeth, called wisdom teeth, then appearing to fill up the more spacious jaw.

401. *The spine or back bone,* in its structure, has as much of beautiful mechanism as any part of our complex frame. It is the central pillar of support and great connecting medium of the other parts. It has, at the same time, the office of containing within itself, and of proteeting from external injury, a prolongation of the brain, called the spinal marrow, more important to mere animal life than the greater part of the brain itself. It thus unites in itself the apparent incompatibilities of great elasticity, great flexibility in all directions, and great strength, both to support a load and to defend its important contents—as we shall now perceive.

Elasticity.—The head rests on the elastic column of the spine as softly as the body of a carriage rests upon its springs. Between each two of the twenty-four vertebræ, or distinct bones of which the spine consists, there is a soft elastie *intervertebral substance,* about half as bulky as a vertebra, and which yields readily to any sudden jar. Then the spine has a waved or bent form somewhat like an italic *ſ*, as is pereeived on viewing it sideways, oı in profile, and owing to this, also, it yields to any sudden pressure operating against either end. The bending might seem a defect in a column intended to support weight; but the disposition of the muscles around is such as to leave all the elasticity of that form, and a roomy thorax or chest, without any diminution of strength.

Flexibility.—The spine has been compared to a chain, because it consists of many distinct pieces (twenty-four). They are in contact by smooth rubbing surfaces, which allow of a degree of motion in all directions; and a little motion comparatively between each two adjoining pieces becomes a great extent of motion in the whole line.

The *strength* of the spine as a whole, is shown in the fact that a man can carry upon his head or back a weight heavier than himself; and the strength of each separate vertebra surrounding the spinal marrow, is evident in its being a double arch, or strong irregular ring. The spine increases in size towards the bottom, in just proportion, as it has more weight to bear. The articulating surfaces of the spine are so many, and so exactly fitted to each other, and are connected by such number and strength of ligaments, that the combination of pieces becomes, in reference to motion, a much stronger column than a single bone of the same size would be.

402. Considering the great number of parts forming the spine, and their nice mutual adaptation, it might be expected that injuries and diseases of the structure would be very frequent. The reverse, however, under natural circumstances, is true; and while innumerable books have been published on the diseases of almost every other part of the body, few comparatively have appeared on spine-affections, and these have been chiefly of recent date. One reason of this was that fashions unfavourable to female health began to prevail about the end of the last century, particularly the practice of compressing the chest and abdomen by what was called *tight-lacing*, and a considerable proportion of the young ladies grew to womanhood with weakened and crooked spines.—Reform has since been effected; but the subject still merits consideration.

403. To the well-being of the higher classes of animals, a certain amount of exercise of their various parts is not less necessary than their nourishment; and if, during the period of growth, such exercise be withheld by any cause, the body never acquires its due proportions and strength. To prompt young creatures to the required exertion, nature has given them an overflow of life and energy, as evinced in the ever-changing occupations of a child, in the quick succession of its ideas, in its jumping and skipping, and using all the modes of roundabout action to expend muscular energy, instead of seeking, as in after-life, to accomplish its ends in the shortest and easiest ways;—the same

fact being evident among the inferior animals, in the play of kittens, puppies, lambs, &c. But, strongly as nature has thus expressed herself, tyrant fashion, with a usual perversion of common sense, introduced about the time referred to, in England, for young women of the higher classes, a school discipline, directly at war with nature's dictate; so that a stranger arriving from China, might almost have supposed that it was the design here to make crooked and weak spines by that discipline, as it is the design in China to make little feet by the unyielding shoe. The result was the more striking, because the brothers of the female victims, who of course had similar constitutions, were seen to be robust, healthy, and well-formed. A *peasant-girl,* with buoyant spirits, might obey her natural feeling, and at proper times might dance, and skip, and run, until healthy exhaustion needed that repose which was equally allowed; and thus she grew up strong and straight: but the *young lady* was receiving constant admonition to curb all propensity to such vulgar activity, and often, just in proportion as she subdued nature, she received the praise of being *well-bred.* The multifarious studies, also, of the latter came powerfully in aid of the admonition, by fixing her for many hours of every day to the sedentary employments of drawing, music, &c.; and the consequences soon followed of weakness in the body generally from the want of the natural exercise and weakness of the back particularly, from the manner in which the sitting was usually performed. It would be accounted cruelty to make a delicate girl stand all day, because her limbs would tire; but this very cruelty was in almost constant operation against her back, as if backs could not tire, as well as limbs. When allowed to sit down because she had been long standing, great care was taken that the muscles of the back, which still remain in action when one sits, should not be relieved; for, from the idea that it was ungraceful to lean, she was either put upon a stool which had no back, or upon a very narrow chair with a perpendicular back. Neither of these seats relieves the spine, the stool, however, being less hurtful than the chair, because it allows the spine to bend in different ways, so as to rest the different sets of muscles alternately, while the chair keeps the spine constantly upright and nearly unmoved. Such excessive fatigue soon caused the spine, somewhere, to give way and to bend, and the curvature often became permanent. Then a bend taking place in one situation, was immediately followed by an opposite bend above

or below, to keep the centre of gravity of the body over the base, and the curve thus became double, like an italic *ſ*, rendering the distortion complete.

When owing to such unnatural discipline the inclination of the back had once been begun, it was often rapidly increased by the means used to correct it. Strong stiff stays were put on to support the back, as was said, but which in reality, by superseding the action of the muscles placed there by nature as the supports, caused these to lose their strength, and to be unable, when the stays were withdrawn, to perform their office. Longer sittings in the narrow upright chair were then recommended, and sometimes the back was forcibly stretched by pulleys, or the patient was kept all day and night for months together, lying on an inclined board, losing her health:—the only things guarded against being, that the patient should have due exercise and air, and should repose or rest properly when not taking exercise. With many persons the prejudice had at last grown up, that strong stays should be put on at a very early age, to prevent the first approach of the mischief, and that children should always be made to sit on straight-backed chairs, or to lie on hard planes. What would be said of a trainer who should propose to improve the strength and shape of a young race-horse or greyhound, by binding tight splints or stays about its beautiful young body, and then tying it up in a stall! Yet this was the kind of absurdity and cruelty which not long ago was practised in this country towards beings as faultless as nature has formed. A pernicious prejudice, with respect to such curvature or distortion of the spine, long existed, namely, that it was a scrofulous affection; and many mothers concealed it as much as possible, and sought remedy from quacks far from home.

404. *The ribs.*—Attached to twelve vertebræ in the middle of the back there are the ribs or bony stretchers of the cavity of the chest, constituting a structure which solves, in the most perfect manner, the difficult mechanical problem of making a cavity with solid exterior, which shall yet be capable of dilating and contracting itself. Each pair of corresponding ribs may be considered as constituting a hoop, which hangs obliquely down from the place of attachment behind, and so that when the forepart of all the hoops is lifted by the muscles, the cavity of the chest is enlarged.

We have to remark the double connexion of the rib behind, first to the bodies of two adjoining vertebræ, and then to a process

or projection from the lower, thus effecting a very steady joint, and yet leaving the necessary freedom of motion; and we observe the forepart of the rib to be joined to the breast-bone by flexible cartilage, which allows the degree of motion required there, without the complexity of a joint, and admirably guards, by its elasticity, against the effects of sudden blows or shocks.

The muscles which have their origin on the ribs and their insertion into the bones of the arm afford us an example worth remembering of action and reaction being equal and contrary. When the ribs are fixed, these muscles move the arm; and when the arm is fixed, as by resting on a chair or other object, they with equal force move the ribs. The latter occurrence is seen in fits of asthma.

The human skeleton with its naked ribs is so associated in the common mind with thoughts of death and loss of friends, and the terrors of dim futurity, that many persons regard it with a kind of awe and even horror; but the utility to every one of having some knowledge of it has become so apparent that in many schools it is now described and explained. To persons of cultivated intelligence who are led to study it in greater detail, the adaptation so admirable of all the parts to their purposes, and of parts which, being purely mechanical, are easily understood, makes it an object of intense interest. If they delight to find in nature the evidences of the wisdom and goodness which willed the present creation they find many here.

404. *The shoulder-joint* is remarkable for combining great range and variety of motion with great strength. The round head of the shoulder-bone, that it may turn freely in all ways, rests upon a shallow cavity or socket of the shoulder-blade; and the danger of dislocation from this shallowness is guarded against by two strong bony projections above and behind. To increase the range of motion to the greatest possible degree, the bone called the shoulder-blade, which carries the socket of the arm, can itself slide about upon the convex exterior of the chest, having its motion limited, however, in certain directions by its connexion, through the collar-bone or clavicle, with the sternum or bone of the breast.

405. *The scapula or blade-bone,* just spoken of, is remarkable as an illustration of the mechanical rules for combining lightness with strength. It has the strength of the arch from being a little concave, like the "dished wheel" described (in Art. 368),

and its substance is chiefly collected in its borders and spines, with thin plates between, as the strength of a wheel is collected in its rim, spokes, and nave.

406. The bones of the arms, considered as levers, have the muscles which move them attached very near to the fulcra, and very obliquely, so that these muscles, from working through a short distance compared with the displacement of the resistances at the extremities, require to be of great strength. It has been calculated that the muscles of the shoulder-joint, in the exertion of supporting a great weight upon the hand, pull with a force of more than a thousand pounds.

407. Notwithstanding all the securities to the shoulder-joint now described, in the infinite variety of twists, and falls, and accidents to which men in the busy scene of society are liable, the joint is frequently dislocated; that is, the rounded head of the humerus or arm-bone slips from its socket, with instant lameness as a consequence.

In the treatment of dislocations and fractures of the framework of the human body, the surgeon cannot avoid displaying strikingly either his professional skill or want of it. With what ease does the displaced arm or other bone return to its socket under the guidance of the skilful hand! but to what horrible, and often unavailing torture is the patient subjected, when in such a case ignorance dares to act! To a practitioner in this branch, impunity and a quiet conscience can now be secured only by his having a perfect knowledge of anatomy, and familiarity with the laws of mechanical philosophy.

408. *The os humeri*, or bone of the upper arm, is not perfectly cylindrical, but like most of the other bones called cylindrical, it has ridges to give strength, on the principle explained in the chapter "on strength of materials." (Art. 383.)

The elbow-joint is a correct hinge, and so strongly secured that it is rarely dislocated without fracture.

408. *The fore-arm* consists of two bones with a strong membrane between them. Its great breadth from this structure affords abundant space for the origin of the many muscles which go to move the hand and fingers: and the very peculiar mode of connexion of the two bones gives man that most useful faculty of turning the hand round into what are called the positions of pronation and supination,—exemplified in the action of twisting, or of turning a key in a lock.

409. *The wrist.*—The many small bones forming the wrist

have a signal effect in deadening, in regard to the parts above, the shocks or blows which the hand receives.

410. *The annular ligament* is a strong band surrounding the joint, and keeping all the tendons, which pass from the muscles above to the fingers, close to the joint. It answers the purpose of so many fixed pulleys for directing the tendons: without it they would all, on action, start out like bow-strings, producing deformity and weakness.

411. *The human hand* is so admirable, from its numerous sensitive and mechanical capabilities, that an opinion at one time prevailed, that man's superior reason depended much on his possessing such an instructor and such a servant. But, although reason, with hoofs instead of fingers, could never have raised man much above the brutes, and probably could not have secured the continued existence of the species,—still the hand is no more than a fit instrument for the marvellously endowed mind which directs it.

412. *The pelvis*, or strong irregular ring of bone on the upper part of which the spine rests, and from the sides of which the legs descend, forms the central mass of the skeleton. A breadth of bone was wanted here to connect the single column of the spine with the lateral columns of the legs, and a circle was the lightest and strongest. If we attempt still farther to conceive how a circle might be modified so as to fit it—for the spine to rest on, for the heads of the thigh-bones to roll in, for muscles to spring from, both above and below, for the person to be able to sit upon, &c., we shall find that all such anticipations of what was desirable are realized in the most complete manner.

413. *The hip-joint* exhibits the perfection of the ball-and-socket articulation. It allows the leg to turn on its axis and to move the foot round in a circle, as well as to have the great range of backward and forward motion, exhibited in the action of walking. When we see the elastic tough smooth cartilage which lines the deep socket of this joint, and the similar glistening covering of the ball or head of the thigh-bone, and the lubricating synovia poured into the cavity by appropriate secretories, and the strong ligaments giving strength all around, we feel how far the most perfect of human works fall short of mechanism exhibited in nature.

414. *The femur* or *thigh-bone* is remarkable for its two projections near the top, called trochanters, to which the chief muscles

are attached, and which lengthen considerably the levers by which the muscles act. The shaft of the bone is not straight, but has a considerable forward curvature. Short-sightedness might suppose this a weakness, the bone being a pillar to support a weight; but the bend gives it in reality the strength of the arch, to bear the action of the mass of muscles called *vastus*, which lies and swells upon its anterior surface.

415. *The knee* is a hinge joint of complicated structure, claiming the most attentive study of the surgeon. The rubbing parts are flat and shallow, and therefore the joint has little strength from form; but it derives security from the numerous and singularly strong ligaments which surround it. The ligaments on the inside of the knees resemble, in two circumstances, the annular ligaments of joints, *viz.*, in having a constant and great strain to bear, and yet in becoming stronger always as the strain increases.

In the knee there is a singular provision of loose cartilages between the ends of the bones. They have been called friction-cartilages, from a supposed relation in use to friction-wheels; but their real effect seems to be, to accommodate, in the different positions of the joint, the surfaces of the rubbing bones to each other.

Under the head of *Pneumatics*, we shall find that the bones forming the joints are held everywhere in smooth contact, independently of their ligaments, by a constant soft pressure of the atmosphere, amounting in the knee, for instance, to upwards of sixty pounds.—(Art. 542.)

416. The great muscles on the fore-part of the thigh are contracted into a single tendon a little above the knee, over and in front of which that tendon has to pass to reach the top of the leg, where its attachment is. The part of the tendon in front of the joint becomes solid or bone, and forms the patella or knee-pan, often called the pulley of the knee. This peculiarity enables the muscles to act more advantageously, by increasing the distance of the rope from the centre of motion. The patella is moreover a sort of shield or protection to the fore-part of this important joint.

The leg below the knee, like the fore-arm already described, has two bones. These offer spacious surface of origin for the numerous muscles required for the feet and toes, and they form a compound pillar of greater strength than the same quantity of bone as one shaft would have had. The individual bones also

are angular instead of round, hence deriving greater power to resist blows, &c.

417. *The ankle-joint* is a perfect hinge of great strength. There is in front of it an annular ligament, by which the greater part of the tendons passing downwards to the foot and toes are kept in their places. One of these tendons passes behind and under the bony projection of the inner ankle, in a smooth appropriate groove, exactly as if a little fixed pulley were there.

418. *The heel,* by projecting so far backwards, is a lever for those strong muscles to act by, which form the calf of the leg and terminate in the tendo Achillis. The muscles, by drawing at it, lift the body, in the actions of standing on the toes, walking, dancing, &c.

419. In a graceful human step the heel is raised a little before the foot is lifted from the ground, as if the foot were part of a wheel rolling forward; and the weight of the body, thus supported by the muscles of the calf of the leg, as just described, rests for the time on the fore-part or ball of the foot and the toes. There is at that time a considerable bending of the foot. But where strong wooden shoes are used, or any shoe with sole so stiff that it will not yield and allow this bending, the heel is not raised at all until the whole foot rises with it, so that the muscles of the calf are scarcely used, and in consequence they soon dwindle remarkably in size. Many of the English farm servants wear heavy stiff shoes, and in London may be seen as the drivers of country waggons, with fine robust body and arms, but with legs which are almost spindles, producing a gait very awkward and unmanly. The brothers of these men, otherwise employed, are not so mis-shapen; and even they themselves, when they chance to become soldiers, and are trained in military exercises, lose their peculiarity. It is to be regretted that, for the sake of a trifling saving of expense, correct nature should be thus deformed.—An example of an opposite kind was formerly seen in Paris, where, as the streets had no side pavements, and the ladies consequently had to walk almost constantly on tiptoe, the great action of the muscles of the calf gave a conformation of the leg and foot, to match which the Parisian belles proudly challenged all the world,—not aware, probably, that it was a defect of their city to which the peculiarity was due.

420. That men lose not a little of the strength and command

of their lower limbs by being condemned to use too small or too rigid shoes cannot be doubted; and the fact is not of small importance to a military people, for the result in battle of a charge where bayonets clash must depend almost as much on the strength of the legs as of the arms.

A person confined to bed for a week or two by illness has generally to remark a much greater wasting of the legs than of the arms; the reason of which is, that the muscles of the leg being more in use than those of the arms, their ordinary bulk is more dependent on use, and they suffer a corresponding change from inaction.

421. *The arch of the foot* is to be noticed as another of the many provisions for saving the body from shocks by the elasticity of the supports. The heel, and the ball of the toes, are the two extremes of the elastic arch, and the leg rests between them.

This explains why the measure of a person's foot taken when seated is considerably less both in length and breadth than when the person stands, with the weight of the body acting to expand the foot. And it helps to explain why boots and shoes are often made too small. But it is a whim of unreasoning fashion which holds that the human foot, as given by nature, is improperly large, and requires to have its growth controlled by the use of tight shoes. Persons who act on this notion often have painful corns or bunions on their feet, and distorted toes, &c., as effects of the pressure, so that the act of walking is rendered a torment. There is the farther evil that the general health and spirits and the bodily appearance and carriage are seriously damaged from want of the due amount of walking exercise in the open air. Over the vast empire of China this absurdity is carried to an extent which is monstrous. Tight bandages are kept on the feet of the children from an early age, and the females of the higher classes become truly cripples for life. The practice seems to be a sister folly to that of letting the finger nails grow to a hideous length within cases worn to defend them. Both deformities seem intended to show that the individuals are of a high order, not requiring to use either feet or hands to gain a livelihood.

422. Connected with elasticity, it is interesting to remark how imperfectly a rigid wooden leg answers the purpose of a natural leg. The centre of the body, when supported by the wooden leg, which remains always of the same length, must describe, at each step, an exact portion of a circle, of which the bottom nob

of the leg is the centre; and the body is therefore constantly rising and falling somewhat like an animal advancing by leaps; but with the natural legs, which, by gentle flexure at the joints, are made shorter or longer at different parts of the step as required, the body is carried along softly in a manner nearly level. In like manner, a man riding on horseback, if he keep his back upright and stiff, has his head jolted by every step of the trotting animal; but the experienced horseman, even without rising in the stirrups, by letting his back yield a little at every movement, as a bent spring yields during the motion of a carriage, can carry his head smoothly along.

423. The muscular force of man has been used as a working power in various ways, as in lifting and carrying a weight—pulling at a rope, turning a winch—walking in the inside of a large wheel to move it, as a squirrel moves his little wheel, &c. Each of these has some peculiar advantage; but the mode in which, for the purpose of lifting weights, the greatest effect may be produced, is for the man to carry up to a height his body only, and then to let it raise a load equal to itself by its weight in descending. A bricklayer's labourer would be less fatigued, while lifting bricks to the top of a house by ascending the ladder without a load and then raising bricks of nearly his own weight over a pulley each time in descending, than by carrying fewer bricks and himself up together, and working down again without a load, as is still usually done in accordance with old habit. Reflection, independently of experiment, would naturally anticipate such result, for the load which a man should be best able to carry is surely that from which he can never free himself,—the load of his own body. Accordingly the strength of muscles and disposition of parts are all such as to make his body appear light to him.

Animal power being exhausted in proportion as well to the time during which it is acting as to the intensity of force exerted, there may often be a great saving of power by doing work quickly, although with a little more exertion during the time. Suppose two men of equal weight to ascend the same stair, one of whom takes only a minute to reach the top, and the other takes four minutes, it will cost the first but a little more than a fourth part of the fatigue which it costs the second, because the exhaustion has relation to the time during which the muscles are acting. The quick mover must have exerted more force in the first instant, to give his body the greater velocity

which was afterwards continued, but the sloth supported his load four times as long.

A healthy man will run rapidly up a long stair, and his breathing will scarcely be quickened at the top; but if he walk up very slowly his legs will feel considerable fatigue, and the body generally may sympathize.

For the same reason coach-horses are sometimes spared by being made to trot quickly up a short hill, and being then allowed to go more slowly, so as to rest at the top.

The rapid waste of muscular strength which arises from continued action is felt by keeping an arm extended horizontally for some time. Few persons can continue the exertion beyond a minute or two. In animals which have long projecting necks there is a singular provision of nature in a strong elastic substance on the back or upper part of the neck, which nearly supports the head independently of muscular exertion.

In further illustration of the truth that strength is saved in many cases by doing work quickly, we may recall the fact explained in Art. 180, that a body thrown or shot upwards with double velocity, rises four times as far as when shot with a single velocity, or half of the other.

424. In a general review of the skeleton, we have to remark, 1st, the nice adaptation of all the parts to one another, and to the strains which they have respectively to bear; as—in the size of the spinal vertebræ increasing from above downwards—the bones of the leg being larger than those of the arm, and so on. 2ndly, the objects of strength and lightness combined; as by the hollowness of the long bones—their angular form—their thickening and flexures in particular places where great strain has to be borne—the enlargement of the extremities of the bones to which the muscles are attached, lengthening the levers by which these act, &c. 3rdly, we have to remark the nature and strength of material in different parts, so admirably adapted to the different purposes to be served; there is bone, for instance, in one place nearly as hard as iron, where, covered with enamel, it has the form of teeth, and the office of chewing and tearing all kinds of matter used as food; in the cranium, again, bone is softer, but tough and resisting; in the middle of long bones it is compact and little bulky, to leave room for the swelling during action of the muscles lying there; while, at either end, with the same quantity of matter, it is large and spongy, to give a broad

surface for articulation: and in the spine, the bodies of the vertebræ, which have between each two an elastic bed of intervertebral substance, are light and spongy, while their articulating surfaces and processes are very hard. In the joints we see the tough elastic smooth substances called cartilage covering the rubbing ends of the bones, defending and padding them, and destroying friction. In infants we find all the bones soft or gristly, and therefore calculated to bear with impunity the falls and blows incidental to early age; and we see certain parts, where elasticity is necessary or useful, remaining cartilage or gristle for life, as at the anterior extremities of the ribs. About the joints we have to remark the ligaments which bind the bones together, possessing a tenacity scarcely equalled in any other known substance; and we see that the muscular fibres, whose contractions move the bones and thereby the body,—because they would have rendered the limbs clumsy even to deformity had they passed unchanged over the joints to the parts which they have to pull,—attach themselves at convenient distances from the joint to a strong cord called a tendon, by means of which, like a hundred sailors at a rope, they make their effort effective at any distance. The tendons are remarkable for the great strength which resides in their slender forms, and for the lubricated smoothness of their surfaces. Many other striking particulars might be enumerated, but these may suffice. Such, then, is the skeleton or general framework of the human body; a less attractive study to ordinary minds than some other parts of the system yet to be examined, but so perfect and so wonderful, that the mind which can attentively consider it without elevating emotion, is in a state not to be envied.

425. This section sets forth some of the reflections which an examination of the skeleton suggests to a person who has studied elementary mechanics; and it may show that the farther the study is carried, the more numerons are the points connected with health on which such knowledge sheds a guiding light, dissipating doubt and error. It may serve also to prove that not only to professional men, but to persons generally, such knowledge is of great importance.

PART III.

THE PHENOMENA AMONG FLUIDS.*

SECTION I.—HYDROSTATICS.

ANALYSIS OF THE SECTION.

The particles in a fluid mass are freely moveable among one another, so as to yield to the least disturbing force; and therefore can be at rest only when the forces acting on them, as that of gravity, &c., balance one another.

1. *In a mass of confined fluid submitted to compression, the whole is equally affected, and equally in all directions. A given pressure, for instance, made by a plug forced inwards upon a square inch of the surface of a fluid filling a vessel, is suddenly communicated to every square inch of the vessel's surface, however large, and to every inch of the surface of any body immersed in the fluid.*
2. *In any fluid, the particles that are below bear the weight of those that are above, and there is, therefore, within the mass, a pressure increasing exactly with the perpendicular depth, and not influenced by the size, or shape, or position of the containing vessel.*
3. *The open surface of a fluid becomes level; and if various pipes or vessels communicate with each other, any fluid admitted to one of them will rise to the same level in all.*
4. *A body immersed in a fluid displaces exactly its own bulk of the fluid, which quantity having been just supported by the fluid around, the body is supported or buoyed upward with a force exactly equal to the weight of the fluid displaced, and must sink or swim according as its own weight is greater or less than this. By comparing therefore the weight of a body with the force which holds it up in a fluid, the comparative weights of equal bulks of the two, or the* specific gravities *are found.*

* Read again the Synopsis, page 1.

"Fluid."

426. It was explained in Part I. that the same atoms may exist in the form of a solid or of a fluid; and that as a fluid, they may either constitute a dense liquid like water, or a light elastie mass like air. A pound of ice, or a pound of water, or a pound of steam, differ only in the particles being more or less distant from each other, owing to the different quantities of heat among them. In the ice, they are comparatively near, and are held together by attraction, as if they were spitted or glued to each other; in the water, the repulsion of heat seems nearly to balance attraction, and to leave the particles at liberty to glide about among each other almost without friction; and in the steam, the repulsion altogether overcomes the attraction, and the particles separate to a great distance, as if held apart by some bulky elastic medium. The few facts not evidently reconcilable with this simple explanation of so many phenomena,—as that water in freezing increases in volume, instead of contracting, like things in general,—and that baked clay, in proportion as it is more heated, contracts instead of dilating,—are treated of in other parts of our work.

Whether matter be in the solid or fluid form, the properties of the individual atoms remain unchanged, that is, the atoms always exist in accordance with the "general truths:" but as, in the chapter on Mechanics, we found many important modifications of effect produced by the circumstance of the attraction being in the degree which produces solid cohesion among the particles, so in this chapter on fluids we shall find as many important results springing from the circumstance of non-cohesion or fluidity.

In a liquid the particles, although comparatively near to one another, seem not to be in actual contact; for the mass may be condensed more and more by pressure. The force required, however, to change the volume of a liquid in any sensible degree, is so great, that until improved means of experiment were recently contrived, liquids were accounted absolutely incompressible. In aëriform fluids, on the contrary, each particle, under common circumstances, has about two thousand times as much space to itself as when forming part of a liquid or solid; and hence it is that these fluids are so extensively compressible and dilatable—or elastic, as they are called. On account of this elasticity, they exhibit so many important phenomena, in addi-

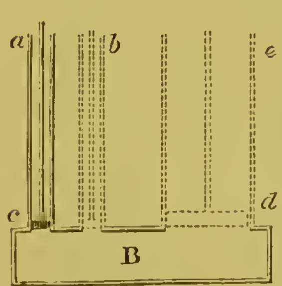
tion to those of mere fluidity, that the consideration of them requires to be gone into apart, and forms the branch of the subject called *Pneumatics,* from a Greek word, signifying "spirit" or "breath."

427. *"In a quantity of fluid submitted to compression, the whole mass is equally affected, and similarly in all directions. A given pressure, therefore, made upon an inch of the surface of a fluid confined in a vessel, as by a plug forced inwards, is suddenly borne by every inch of the internal surface of the vessel, however large, and by every inch of the surface of any body immersed in the fluid."*

This truth is of great importance, both from its explaining so many remarkable phenomena of nature, and from the useful applications of it in the construction of machinery.

428. When a man compresses in his hand a bladder full of air, he readily conceives that the air immediately under his fingers is not at all more compressed, than that in every other part of the bladder; and of course that every part of the bladder's surface must be pressing the air as much as those parts of it on which his fingers rest, and must be bearing a reaction or resistance of the air in an equal degree; and that every single particle of air must be acted upon equally on every side, so that if a small opening were made in the bladder anywhere, the air would issue from it with equal readiness. This is in accordance with the characteristic of fluidity, "that the particles glide about among one another almost without friction, so that a particle can never be at rest unless when equally urged in all directions."

429. In like manner, if a close vessel B be filled with water, and into the top of it a tube *a c* be screwed, and if then, by means of a cork or moveable plug in the tube at *c*, the surface of the water in the vessel be pressed upon with a force of one pound, the water throughout the whole will be squeezed or condensed in proportion to the pressure, and every other portion of the vessel B, of equal surface with *c*, will be keeping up the condensation just as much as *c*, and will be bearing the resistance or elasticity of the water to the extent of one pound. And if there

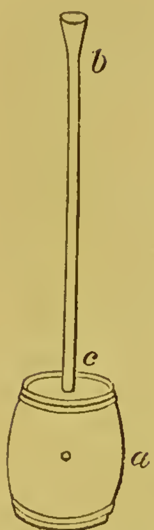


were another similar tube *b*, also with a plug, screwed into the top of the box B, the force of one pound depressing the plug *c* would be pushing up the plug *b* with the same force. And if there were many other similar tubes and plugs, by acting on one, all would be equally affected; and a plug or piston of double area would be twice as much affected as the smaller one; and a plug *d*, of ten times the area, would be lifted with a force of ten pounds. Hence it appears that, through the medium of a confined fluid, a force of one pound, acting upon an inch square of the fluid surface in a vessel, may become a bursting force of ten or a hundred or a thousand pounds, according to the size of the vessel, or may be used as a mechanical power to overcome a force much more intense than itself. It will be explained below that the well-known hydrostatic press is merely a large plug or piston as here described, forced up against the substance to be pressed by the action of a smaller piston in another barrel.

430. If in the above figure the tube *a* were such as to contain just one pound of water, on the plug *c* being withdrawn from it, and water being poured in to fill it, the same pressure or condensation would take place in the box B as when the plug was pressed with the force of one pound; and of course exactly the same effects would follow on the sides of the vessel and on the other pistons: and if in the other tubes also, water were substituted for the pistons, it is evident that, to effect a balance in all, it would require to stand as high in every one as in the tube *a c*, producing thus the same level in all, whatever their size.

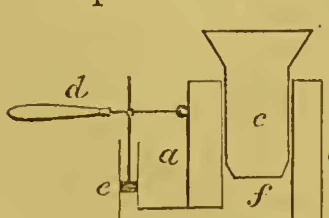
431. The fact, that the weight of one pound of water, or any other force of one pound similarly applied, may be made, through the medium of extended fluid surface, in a closed vessel, to produce a pressure of hundreds or of thousands of pounds, has been called the "hydrostatic paradox;" yet there is nothing in reality more paradoxical in it than one pound at the long end of a lever should balance ten pounds at the short end: indeed it is but another means, like the contrivances usually called mechanical powers, and described in the last chapter, of causing different intensities of force to balance each other, by applying them to parts of an apparatus moving with different velocities. Here the tube *a* being ten times smaller than the tube *e*, the piston in *a* must descend ten inches to raise the greater piston in *e* one inch.

432. This law of fluid pressure is rendered very striking in the experiment of bursting a strong cask by the weight or action of a few ounces of water. Suppose a cask *a* already filled with water, and that a long small tube *b c* is screwed tightly into its top, which tube can contain only a few ounces of water; by pouring these few ounces into the tube, the cask will be burst. In explanation, it is unnecessary to say more than that if the tube have an area of a fortieth of an inch, and contain, when filled, half a pound of water, that water would produce a pressure of half a pound upon every fortieth of an inch all over the interior of the cask, or of nearly 2,000 lbs. on every square foot,—a pressure greater than a common cask can bear.



433. A similar effect is seen in what is called the *hydrostatic bellows*. This consists of a long small tube *a b*, into which water is poured to enter the body of the apparatus at *c*, which resembles the common bellows, in having wooden boards above and below, and strong sides of leather connecting them. If the tube *a b* holds an ounce of water, and has itself only one-thousandth of the area of the top of the bellows, an ounce of water in it will balance weights of a thousand ounces placed on the top of the bellows at *d*. If mercury were substituted in this machine for water, the effect would be thirteen and a half times greater, because mercury is so many times heavier in the same bulk. And if a man stand on a large bellows of the kind, he may raise himself by blowing into the tube with his mouth.

434. The annexed cut will give an idea of Mr. Bramah's singularly powerful and useful *hydrostatic* or *hydraulic press;* which, if compared with the bellows, exhibits merely a strong forcing pump instead of the lofty tube, and a barrel with its piston instead of the leather and boards. The letter *e* points out the piston of the forcing pump worked by the handle *d*, and driving water along the horizontal tube into the space *f* under the large solid piston *c*, which last, with its spread-



ing top, is urged against the object to be compressed. If the small pump have only one-thousandth of the area of the large barrel, and if a man, by means of its lever-handle *d*, press its piston down with a force of a hundred pounds, the piston of the great barrel will rise with a force of a hundred thousand pounds. Scarcely any resistance can withstand the power of such a press; with it the hand of a child can break a strong iron bar. It is used to condense bulky yielding substances, as cotton or hay for sea voyages, to raise great weights, to uproot trees, to test the strength of materials, and so forth.

435. "*In any fluid, the particles that are below bear the weight of those that are above, and there is therefore a pressure among them increasing in exact proportion to the perpendicular depth, and not influenced by the size, or shape, or position of the containing vessel.*"

436. The atoms of matter having gravity, it is evident that he upper layer of any mass of fluid must be resting on or supported by the second, and this with its load by the third, and the third with its double load by the fourth, and so on. This truth is experimentally proved by putting different heights of liquid into an upright tube, of which the bottom is closed by a flap having a spring or lever to support it, and which indicates the force acting on it. And what is true of the entire column of water in the tube, may be considered true of any vertical line of its atoms, as of a line of bricks, with this important difference, however, that whereas the bricks, having flat parallel surfaces of contact above and below, rest on each other without producing any pressure sideways, the particles of fluids, as if round or not in positive contact, tend to escape from their mutual upward and downward pressure in all other directions equally.

437. A tube of which the area is an inch square, holds, in two feet of its length, nearly a pound of water; hence, the general truth, well worth recollecting, that the pressure of water at any depth, whether on the side of a vessel or on its bottom, or on any body immersed, is only a little less than of one pound on the square inch for every two feet of depth.

The striking effects from the increase of pressure in a fluid, at great depths, are of course most commonly exhibited at sea. The following instances will illustrate them.

438. If a strong square glass bottle, empty, and firmly corked,

be sunk in water, its sides are generally crushed inwards by the pressure before it reaches a depth of ten fathoms.

A chamber constructed of wooden plank and containing air, if similarly let down with a man in it, would quickly allow him to be drowned by the water bursting in upon him;—as really happened to an ignorant projector while making an experiment.

When a ship founders in shallow water, the wreck on breaking to pieces generally comes to the surface, or floats, and is cast upon the beach; but when the accident happens in deep water, the great pressure at the bottom forces water into the pores of the wood, and renders that so heavy that no part can ever rise again to reveal her fate.

A bubble of air or of steam, set at liberty far below the surface of water, is small at first, owing to the compression, and gradually enlarges as it rises.

439. A man who dives deep, suffers much from the compression of his chest, as the elastic air within yields under the strong pressure. This fact limits the depth to which ordinary divers can safely go.

It is not known whether there is a limit to the pressure which fishes can bear with impunity, but they abound chiefly in the shallower waters on coasts, or on banks in the midst of the ocean, such as the banks of Newfoundland, the Dogger-bank, and other fishing stations out at sea. In rounding the Cape of Good Hope, at a considerable distance from land, ships pass over the bank of Lagullas, where a hook let down with a bit of red rag or almost anything as a bait, immediately secures its cod-fish,—as the writer of this had the opportunity to observe.

440. By sending a vessel, prepared for the purpose, down into the deep sea, the compressibility of water can be proved. Suppose the vessel to be made with one entrance, in the form of a small round opening, into which, instead of a cork, a sliding rod has been closely fitted. If then, when filled with water, and with the rod inserted, it be allowed to sink in the sea, the pressure around will push the rod inwards, in a degree proportioned to the yielding or compression of the water within: and if there be on the rod a stiff-sliding ring, or other contrivance to indicate on the return of the vessel how far, when low down, the rod had been driven inwards, the apparatus shows the degree of compression at the greatest depth to which it has descended. Water compressed by a force of 15,000 lbs. to the

square inch, or 1000 fathoms of water over it, loses about one-twentieth part of its bulk.

441. The following are proofs of the pressure produced by weight in an open fluid, operating in all directions, as any pressure does in the case of a confined fluid.

A bottle-cork compressed under water, is not flattened as if it were pressed unequally, or only above and below, but is reduced in all its dimensions, so as to appear a phial-cork of the usual form.

442. If a vessel containing water have an opening in the side, closed externally by a valve or flap so contrived as to tell the force required to keep it shut, we find that the water tends to escape just as powerfully through such an opening as it would through an opening in the bottom, with the same elevation of water over it. And different equal openings in the side of a vessel require to be closed with forces exactly proportioned to the heights of liquid above them.

443. In an open square-sided vessel full of water, the whole pressure on any upright side is just half the pressure on an equal extent of horizontal bottom; for the centre of the side being just half as deep as the bottom, the pressure on any point there is only half as great as on a point at the bottom, and on points above the level of the centre is just as much less than half, as, at corresponding distances below, it is more than half, and so it amounts to an exact half in the whole. Considering that the pressure on every point below the central level is greater than on every point above it, we see the reason why, to support a sluice or flood-gate by a single stay on the outside, the point at which the pressure has to be made is below the central level. Calculation and experiment discover that this point, called the centre of pressure, is at one-third from the bottom. The knowledge of such facts furnishes rules for the construction of large vessels to hold liquids, and of canal and other embankments.

444. The pressure on the upright side of a deep narrow vessel is just as great as on the same extent of the side of a wide vessel, having the same depth of fluid: because, as now explained, it depends entirely on the extent of surface acted upon, and the depth of liquid.

Hence a flood-gate or sluice which shuts out the ocean, as in docks opening to the sea, bears no more pressure than if it

stood only against an equal depth of lake or river; and if it were one of two such flood-gates, forming the sides of a flat vessel, so narrow that a few hogsheads of water would fill it, the pressure on it would be still the same.

A deep crevice in a rock, if filled by rain, may cause the rock to split or be torn asunder.

445. Extensive walls or faces of masonry, intended to confine banks of sand or earth, if left without low openings for water to escape from behind them, may be burst after rain, unless they have the strength of flood-gates of the same size. Ignorance of this danger has led to some extraordinary catastrophes.

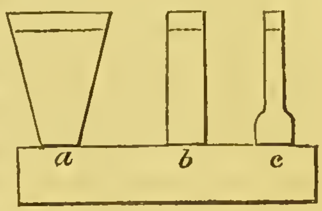
446. Other examples of the pressure in fluids being exerted in all directions, and proportioned always to the depth, are;—the swelling and bursting of leaden pipes when filled from a very elevated source:—the tearing up of the coverings of subterranean drains or water-courses, when during a flood any accident chokes them near their lower openings:—the violence with which water escapes by an opening near the bottom of any deep vessel, or enters by an opening or leak near the keel of a deep-floating ship:—the great strength required in the lower hoops and securities of those enormous vessels of porter-brewers, called vats, some of which contain thousands of barrels of liquid.

447. In speaking of the pressure of a fluid in all directions, some persons have difficulty in conceiving that within a fluid there is an upward as well as a downward and a lateral pressure. But, if in any fluid mass, the particles below at every point had not a tendency upwards equal to the weight or downward pressure of the fluid over them, they could not support that fluid, but would move away, which they do not. Their tendency upwards is owing to the pressure around them from which they are trying to escape. If a long tube, open at both ends, and with a sliding plug or piston in it near one end, be partially plunged into water by the plugged end, the water is found to press the plug upwards with force proportioned always to the depth to which it is carried, and exactly equal to the force with which water presses upon an equal extent of the bottom or side of any other vessel having in it the same depth. On removing such a plug altogether, the upward pressure is visibly proved and measured by the column of water pushed into the tube from below, and supported there to the level of the water around.

448. The pressure in a mass of fluid, is proportioned to the perpendicular depth, and is not at all influenced by the size, shape, or position of the containing vessel.

A body immersed in the water of a lake, one foot under the surface, is just as much pressed upon, as if it were one foot under the surface of the sea, and no more than if it were one foot under the surface of a small cistern.

449. Suppose vessels differing from each other in form and capacity, as sketched here at *a*, *b*, and *c*, but all having flat bottoms, of exactly the same area; if fluid be poured into all to the same level or perpendicular height, as represented here by the dotted lines, although the quantity be very different in each, the pressure on the bottom will be the same in all.



This truth is easily proved experimentally, by having the bottoms moveable, and held to their places by weights or springs capable of indicating the pressure borne: or by letting the three vessels all communicate with the same vessel of water below them, and then observing that the water in all is supported at the same level.—These results are further exemplifications of the truths, "*pressure equal in all directions*," "*pressure as depth*," and "*pressure as the extent of surface*." For as a column of the fluid, resting on the middle of each bottom, just presses with its whole weight, and therefore according to its altitude, this column could not remain at rest if there were any greater or less pressure than its own acting around it; then as the fluid really is at rest in all the cases, and in all the central column is of the same height, the pressure must be equal on all the bottoms. The case of the largest vessel *a* is in a degree illustrated by supposing the water in it to be suddenly converted into smooth upright small columns or rods of ice or glass; then evidently, only those pieces which rested on the bottom, could press on it, while the others would be supported by the oblique sides of the vessel, and by the lateral resistance of the pieces near the centre.

450. "*Level surface of a fluid.*" (Read the Analysis.)

That the surface of a fluid must be level, follows from the facts of all the particles being equally attracted towards the centre of the earth, and being perfectly moveable among themselves. The particles forming the surface may be regarded as

the tops of so many columns of particles, supported by a uniform resistance or pressure below;—for no particle below can be at rest unless equally urged in all directions, and therefore all the particles at any one level, and which, by equally urging one another, keep themselves at rest, must all be bearing the weight of equal columns: thus a higher column, however produced, must sink and a lower one must rise, until just balanced by those around; that is, until all become alike. Besides, just as a ball rolls down a slope or inclined plane, so do the particles of a fluid slide or move from any higher situation among themselves, to any lower unoccupied situation near them. The account now given explains why the accidental elevation or depression of a fluid surface, called a wave, continues to rise and fall, or to oscillate, for some time with gradually diminishing force;—for when the mass is raised above the general level, it is not quite supported, and therefore soon sinks, but in sinking, like a falling pendulum, it acquires momentum which carries it below the general level, until opposed and arrested by a resistance greater than its weight, it then rises again, but by acquiring new momentum in its rise, it has to fall again, again to rise, and this alternation continues, until the lateral sliding of the particles, and the friction among them, gradually destroy it.

A perfectly level surface on earth, really means one in which every particle of it is equi-distant from the centre of the earth, and it is therefore truly a spherical surface like that of the earth; but so large is the sphere, that if a slice of it of two miles in diameter were cut off, and laid on a perfect plane, the centre of the slice would be only four inches higher than the edges. Any small portion of it, therefore, for all common purposes, may be spoken of as a plane.

So truly smooth does a fluid surface become, that it forms a perfect mirror; that is, it reflects or throws back the rays of light which fall upon it so exactly in the order which they had on leaving the object, that an eye which receives them, may fancy the object to be placed in the direction of the mirror.—It was over the glassy surface of the fountain or the lake, that the shepherdesses of the young world bent themselves, to learn how highly nature had favoured them. And a child contemplates with wonder and delight, through the apparent window of a still pool, another sky below the ground, with its clouds, and sun or stars; and another landscape, with inverted trees and mountains, the fancied dwelling of fairy beings.

451. In the cutting of canals, the making of railways, and in many other operations of engineering, it is of essential importance to determine the level or horizontal direction at any place. A simple means for the purpose is the plummet described in Art. 156. Another means still more delicate is a tube or glass *a c*, filled with spirit except one bubble of air *b*, and called a spirit level. When this tube is horizontal, the bubble has no tendency to move to either end; but if the tube inclines ever so little, the bubble rises to the end which is highest; or, to speak more correctly, the denser spirit falls down to the lower end, and forces the light bubble in the opposite direction upwards. Such a tube properly fixed in a frame, with a telescope attached to it, becomes the engineer's guide in many of his most important operations.

A hoop surrounding the earth would bend away from a perfectly straight horizontal line four inches in the first mile. In cutting a level canal, therefore, which may be considered as part of such a hoop, there must be everywhere a falling from the straight line called *a tangent,* in the proportion now described. All rivers also must have this curvature, and a little more, to produce the running motion.

452. Canals leading from seaports to the interior of countries have generally to ascend; but as water cannot become stagnant in any channel which is not level, the canal is divided, by gates or sluices, into portions at different levels, like steps of a stair, the rising at these gates being generally from six to twelve feet. The boats are raised or lowered from one level to another by the contrivance called a lock, which is merely a portion of the canal, of sufficient length for the boat to lie in, furnished with high walls, and with flood-gates at both ends; so that when the gates below are shut, and water is admitted from above, the lock becomes part of the high level, ready as such to receive a boat, or to deliver one: and when the upper flood-gates are shut, and the water is gradually allowed to escape from below, the lock becomes a part of the low level, and a boat may enter it or leave it by its lower gates.

The cutting of canals is one of the great items in the mass of modern improvement, which both mark and hasten the progress of civilization. Adverting to the importance of easy intercourse, as explained in a former section (Art. 371), we need only say here, that a horse which can draw but one ton

on our best roads, can draw thirty with the same speed in a canal-boat.

453. And what a glorious triumph to science and art it is, to be able to conduct vessels of all kinds, even those originally intended for the ocean surge alone, through the quiet valleys of an interior country! In Scotland, now, along the Caledonian canal, a noble frigate may be seen, wandering as it were among the inland solitudes, and displaying her grace and majesty to the astonished gaze of the mountain shepherd; and when she has traversed the kingdom, and visited the lonely lakes, whose waters formerly had borne only the skiff of the hunter, she descends again by the steps of her liquid stair, and safely resumes her place among the billows.

454. It has been in contemplation to lead a ship canal across the isthmus of Panama which joins North and South America. The elevation to which a canal must rise, to surmount the central ridge there, is considerable; but such important consequences would follow the accomplishment of the object, that, with the advent of general peace, and the increase of political wisdom, it may be attained. If so, the loaded vessel, ascending from the Atlantic, would for a time be descried among the mountain heights, and after a few hours, would be safely at anchor in a port of the opposite sea; having performed, by a near cut, a voyage which at present costs months of delay and hazard, in a tedious navigation round the whole southern continent.—If the Red Sea and Mediterranean can be joined in the same way, as is now being attempted with hope of success, the operation would, in effect, bring India nearer to Europe, and would more and more strengthen bonds of union among the nations of the earth. Then, indeed, might it be said with truth, that the world is a vast garden, given to man for his abode, of which every part offers different and peculiar objects of value; but, because the inhabitants of each may exchange shares of their wealth for shares in return, the same general result follows as if every field or farm contained within itself the climates and soils and capabilities of the whole.

In a canal, the least deviation from the true level would immediately cause water admitted into it to flow towards the lower end. This flux to a lower situation is what is going on in the myriads of streams, which render the face of the earth a scene of such varied beauty and incessant change.

455. This earth with the circulation of water upon its surface

has been likened to the animal body, with its circulation of renovating blood. In the animal the great moving agent is the heart acting as a forcing pump, and sending the blood charged with fresh nourishment along the arterial channels to every part of the system, and thence back again by veins to the heart to be recharged. In what may be called the living universe, the sun is the great motive agent, whose heat raises into the atmosphere by evaporation from the extended surface of the ocean, as much perfectly pure water as all the rivers of the earth are returning to it of water carrying impurities. The watery vapour is diffused over the whole earth by the motions in the atmosphere called winds, which also are effects of the sun's heat, as will be explained hereafter, and is deposited again everywhere in the forms of rain, dew, snow, &c. Having then served all-important uses to the animal and vegetable creations it glides into descending channels, and simply by the magic power of fluid seeking its level it is ultimately conveyed back to the universal receptacle, the ocean.

456. A very slight declivity suffices to give the running motion to water. Three inches per mile, in a smooth straight channel, gives a velocity of about three miles per hour. The Ganges, which gathers the waters of the Himalaya mountains, the loftiest in the world, is, at eighteen hundred miles from its mouth, only eight hundred feet above the level of the sea—that is, about twice the height of St. Paul's Cathedral in London; and to fall gradually these eight hundred feet, in its long course, the water takes nearly a month. The gigantic Rio de la Plata has so gentle a descent to the ocean, that in Paraguay, fifteen hundred miles from its mouth, large ships arrive which have sailed against the current all the way, by the force of the wind alone: that is to say, which on the gently inclined plane of the stream, have been gradually lifted by the soft wind, and even against the current, to an elevation greater than that of our loftiest spires.

457. A small lake or extensive mill-pond, with uneven bottom, if suddenly emptied by a sluice or opening at its lowest part, would exhibit a number of pits or pools of various size and shape left among the inequalities. But when rain should afterwards fall, and frequently recur, the water seeking its level would soon effect a very remarkable change. In consequence of each pool discharging over its lowest part, that is, sending out

a streamlet either into another lower pool, or into a channel leading directly to the sluice or opening, there would be a constant wearing down of the part or side of the pool over which the water were running, that is to say, a deepening of the breach or channel there, and the surface of water in the pool would be consequently becoming lower, while, at the same time, the bottom would be rising, owing to the deposit on it of sand or mud washed down by the rain from the elevations around; and these two operations continuing, the pool would at last altogether disappear. Then, by this change going on in every pool over the whole of the emptied mill-pond, the general bottom would at last exhibit only a varied or undulated surface of dry land, with a beautiful arrangement of ramifying water channels, all sloping with a precision scarcely attainable by art, to the general mouth or estuary.—The reason that, in the supposed case, and in every other, a watercourse soon becomes so singularly uniform, both as to dimension and descent, is, that any pits or hollows in it are gradually filled up by the sand and mud carried along in the stream, and deposited where the current is slack; while any elevations are gradually worn down by the action of the more rapid current which accompanies shallowness.

458. The above paragraph describes in miniature, what has been going on over the general face of this earth, ever since the sudden local convulsions or more tranquil movements of upheaval and depression which led to the present distribution of land and water on its surface. In many places the phenomenon of the gradual draining is already complete, in others it is only in progress. Geologists have found the proofs clear that much of the present dry land on the globe has in remote time been sea-bottom, and that great part of it had been a gradual deposit from moving water of mud and sand, which by length of time hardened into rock, embedding or preserving within it the innumerable shells, bones, and other remains now found, of the living beings which inhabited the earth during the progress of change. It is thence concluded that our present continents and islands must have been upheaved from the bottom of an ocean, or an ocean must have subsided away from them; and that in either case the land must have emerged as chequered and unsightly, as the bottom of the emptied lake above supposed. —It thus appears that the gradual operation of *water seeking its level,* is that which has converted the earth into the paradise which we now behold.

459. The marks of former states of the world, and of the progressive changes above described are evident even to slight observation of geological facts. In the course of many rivers there are along portions of them extensive breadths of level ground, of which the substance often to great depths is found to consist of the kinds of clay, mud, or sand which the stream is still carrying down from the higher lands, mixed with the buried shells and bones of such animals as have lived in it or on its banks. These plains had been in remote time deep hollows or lakes surrounded by barriers of elevated land, through which the chief passages or depressions were those by which the river now enters and leaves them, which passages had evidently been gradually cut deep by the action of running water.

460. The magnificent river, the Rhine, for instance, has evidently been the drain of a chain of such basins or lakes gradually filled up, which in remote time must have discharged or run over, one into another, but owing to the continued stream cutting a channel at last low enough to empty them all, have become now regions of fertility, occupied by civilized man. This operation is seen to be still going on in all the lakes of the earth. The lake of Geneva, for instance, within the historical period of accurate observation and record has become much shorter and shallower. It is ascertained that since the time of Julius Cæsar an extent of about three miles at its upper part has been filled up and converted into dry land by the wearings of the alpine mountains, brought down by the winter torrents. If, therefore, the town of Geneva last long enough, its inhabitants will have to speak of the river threading the neighbouring valley, instead of the picturesque lake which now fills it. Several towns or villages, which were close upon the lake some centuries ago, have now fields and gardens spreading between them and the shore. Illustrating this subject, it is very interesting to observe the contrast between the proverbially pure blue water of the Rhone issuing from the lake of Geneva at the lower end, and the turbid streams which enter it from above and around. These having deposited all their load of mud, sand, gravel, &c. in the still bosom of the lake, become the pure water of the river below. The streams which join the Rhone below the lake, directly from the Alps, bringing with them their charge of broken-down rocks and earth, even after they enter the common channel, are long distinguishable by their muddy waters.

When in the course of a river there is no lake to intercept

the solid matters which it carries down, these ultimately reach the sea, and form the vast regions of flat country, called Deltas, seen around the mouths of rivers. There is an extensive formation of this kind at the mouth of the Rhone. The greater part of Holland is a similar deposit from the Rhine. The whole of Lower Egypt, and much of the flat fertile land higher up, has thus been formed by the Nile; much of Bengal has been formed by the Ganges, and so forth.

461. There are some lakes on the face of the earth which have no outlet towards the sea,—all the water which falls into them being again carried off by evaporation alone—and such lakes are never of fresh water, because every substance, which, from remotest time, rain could dissolve in the regions around them, has necessarily been carried towards them by their feeding streams, and there has remained. The great majority of lakes, however, being basins with the water constantly running over at one part towards the sea, although all originally impure and salt, have in the course of time become fresh, because their only supply, being directly from the clouds, or from rivers and springs fed by the clouds, is fresh, while that which runs away from them must always be carrying with it a proportion of any substance remaining dissolved in them. We thus see how the face of the earth has been gradually washed to a state of purity and freshness fitting it for the uses of man, and why the great ocean necessarily contains in solution all the substances soluble in water which originally existed near the surface of the earth, and therefore all saline substances. The city of Mexico stands in the centre of a vast and beautiful plain, 7,000 feet above the level of the sea, and surrounded by ridges of mountains of sublime elevation, many of them snow-capped. One side of the plain is a little lower than the other, and forms the bed of a lake, which is salt for the reasons stated above;—but the lake will not long be salt, for it now has an outlet. About 150 years ago, owing to unusual rains, an extraordinary increase of the water took place, and covered the pavements of the city. An artificial drain was then cut from the plain to the lower external country, at the distance of about sixty miles from the city. This soon freed the city from the water, and since then, remaining a constant stream, is still lowering the surface of the lake, is daily rendering the water less salt, and is converting the vast salt marshes, which formerly surrounded the city, into fresh and fertile fields.

Where the soil or bed of a country through which a water-

track passes is not of a soft consistence, so as to allow readily the wearing down of higher parts, and the filling up of hollows by deposited sand, lakes, rapids, and great irregularities of current remain. We have, for instance, the line of lakes in North America, the rapids of the St. Lawrence, and the stupendous falls of Niagara, where at one leap the river gains a level lower by a hundred and sixty feet. A softer barrier than the rock over which the river pours, would soon be cut through, and the line of lakes might be emptied.

462. The contemplation of the fact, that water in seeking its level is constantly wearing where it rubs, and carrying the abraded portions down to lower levels, and ultimately to the bed of the ocean, brings the awful idea, that this earthly abode of ours, owing to natural causes ever in operation, can have but a limited existence in its present state. No shower falls that does not send portions of mountain and plain into the depths of the ocean, and thus cause a corresponding encroachment on the shores by the rising water; and with revolving ages, unless the causes which have operated in past time to upheave portions of the earth's crust from beneath the sea continue to operate, the whole of the present dry land must disappear. Human art may for a time succeed, as in Holland and elsewhere, in shutting out the ocean from some low tracks by means of sea dykes or embankments, but the result of such agency is utterly insignificant, in comparison with what the great laws of nature are everywhere effecting in a contrary direction. It is ascertained (see Lyell's Geology, chap. xix.) that the river Ganges alone carries down every year, and deposits in the bay of Bengal, more solid matter than would cover the whole surface of England to a considerable thickness.—All the changes, however, here referred to, are providentially ruled by Infinite Wisdom.

463. There is, perhaps, no fact which illustrates in a more striking manner the exact accordance of all nature's phenomena, with the few general expressions called laws which describe them, than the steady maintenance of the mean height and level of the ocean as a liquid surface. The sea, although having in most parts a depth of thousands of feet, which fluctuates several feet twice in every day with the flood and ebb-tides, never rises or falls in any place, even one inch, but in obedience to fixed laws, which men can study. Were it not for this perfect exactness, in what a precarious state would the inhabitants exist on

the sea-shores, and on the banks of low rivers! Few of the inhabitants of London, perhaps, reflect, when standing by the side of their noble river, and gazing on the rapid flood-tide pouring inland through the bridges, that, at the moment, the level of the wide ocean around the mouth of their river is several feet higher than that of the water near them.

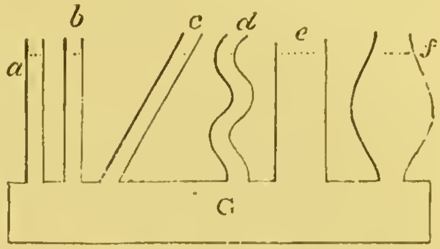
464. The destruction that would follow a slight alteration in the level of the ocean, may be judged of by the effects of occasional floods, produced by rains and melting snow in the interior of countries, or by these combined with winds and high tides on the coasts. The accounts given in historical dictionaries, under the title of *Inundations*, are truly appalling. In Holland, which is a low flat, formed chiefly by the mud and sand brought down by the Rhine and neighbouring rivers, much of the country is really below the level of the common spring-tides, and is only protected from daily inundations by artificial dykes or ramparts, intended to be strong enough to resist the ocean. Partial failures of these have been frequent; and, in the year 1580, a more extensive failure caused an inundation which drowned four hundred thousand people.

465. Where moderate inundation is regularly periodical, as in the Nile and many other rivers, the hurtful effects can be guarded against, and the occurrence may even be highly useful, in fertilizing the soil. Tracts of land in contact with rivers, where the surface lies between the levels of ebb and flood-tide, if surrounded with dykes, may be kept constantly covered with water, by sluices made to open only at high water; or may be kept constantly drained, by sluices which open only at low water. A vast extent of rice-fields, near the mouths of rivers in India and China, are managed in this way, the admission or exclusion of water being regulated by the age of the rice plant, A great part also of the rich sugar plantations of Demerara, Essequibo, &c., on the coast of South America, are in the same predicament.

466. "*If various tubes and vessels communicate with one another, fluid admitted to any one of them will rise to the same level in all.*" (Read the Analysis, p. 160.)

The following sketch may represent a variety of tubes and vessels, fixed upon and opening into the cistern or box *a*. Water poured into any one would fill the box, and would then rise to the same level in all. The dotted lines between *a*

and *f* may represent the surfaces of the fluid in the different vessels. In the figure (Art. 429), it is seen why, in all upright cylindrical vessels, as *a*, *b*, and *e*, the fluid rises to the same level; and the figure in Art. 449, explains why shape of vessel cannot affect the level.



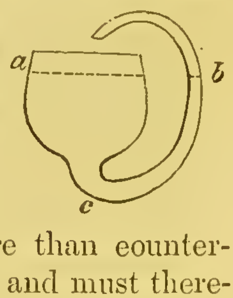
Although in the oblique vessel *c*, represented here, there is more water than in *a*, still there is the same pressure at the bottom of both, because *c* supports part of the weight of its contained fluid on the principle of the inclined plane.

If a tube twenty miles long, and rising and descending among the inequalities of a country, were filled with water, and could have its ends brought together for comparison, it would exhibit two liquid surfaces having precisely the same level; and on either end being raised the fluid would sink in it, and cause overflow from the other.

467. An easy mode of determining a level line at any spot is to have an open tube, bent up at its ends *a* and *b*, and nearly filled with liquid: by then looking along the two liquid surfaces, or through floating *sights* resting on them, an observer looks in a line which is quite horizontal at the middle point between them.

If there were two lakes on adjoining hills of different heights, a pipe of communication descending across the valley and connecting them, would soon bring them to the same level; or if one were much higher than the other, would empty that one into the other.

468. A young projeetor thought he was to solve the renowned problem of the perpetual motion by his invention of the vessel represented here. It was goblet-shaped, lessening gradually towards the bottom until it became a tube, turned upwards at *c*, and pointing with an open extremity into the goblet again. He reasoned thus: A pint or pound of water in the goblet *a* must more than eounterbalance an ounce which the tube *b* will eontain, and must therefore be constantly pushing the ounce forward into the vessel again, and keeping up a stream or circulation, which will cease only when the water dries up—a result easily preventible. He



was confounded when a friend remarked, that a common teapot is nearly such a vessel, and yet does not overflow, and when a trial showed him the same level always in *a* and in *b*.

A glass tube inserted near the bottom of a cask or cistern of any sort, not tightly closed above, which tube is then bent upwards, to appear on the outside like a barometer tube, shows by the elevation of the liquid in it, the exact height of the greater mass of fluid within.

In like manner a tube brought from a river into a neighbouring cellar or pit, will indicate the height of the water in the river.

469. A knowledge of the truth, that water in pipes will always rise to the height or level of its source, has enabled men in modern times to construct those admirable systems of branching iron pipes, which distribute water in great towns. The water being brought or pumped up to any elevated site in or near the town, may be delivered from a reservoir there, by the effect of gravity alone, to every cistern which is under the level of the reservoir; the result not being affected by the size of the pipes, nor by their having to rise over heights and to descend into hollows in their course.

Many persons have believed that the ancients were ignorant of the law, that fluid in pipes rises to the level of its source, because in the ruins of their aqueducts, the channel is a regular slope. Some of these aqueducts are scarcely inferior, as works of magnitude, to the great wall of China, or the Egyptian Pyramids; yet at the present day, a single pipe of cast iron is made to answer the same purpose, and even more perfectly. It is now known, however, that it was not ignorance of the principle, but want of fit material for making the pipes, which cost our forefathers such enormous labour. In particular cases of great magnitude, as that of the Croton aqueduct of New York, the open channel is still the form preferred.

The supply and distribution of water in a large city, particularly since the steam-engine has been added to the apparatus, approaches closely, as already remarked, to the perfection of nature's own work in the arterial system of the animal body. And there will soon exist in London a peculiar system of sloping drains and sewers, already nearly completed, like the venous, which will carry away, without allowing contamination of the river, not only what remains after use, of the artificial water-

supply, but also much of the rain which falls. It is a striking reflection that, by this counter-system of sloping channels, a heavy shower may fall, and after washing and purifying every superficial spot of the city, and sweeping out all subterranean passages, may within an hour, be in the sewers far on its way to the sea. London had already been called the largest and the healthiest capital in the world; and the sanitary works now in progress all tend to justify the appellation.

English citizens have now become so habituated to the blessing of an abundant supply of pure water, that they no more wonder at it than at the regularly returning light of day or warmth of summer. But a retrospect into past times may still awaken them to a quick sense of their obligation to advancing art. How much of the anxiety and labour of men in former ages had relation to the supply of this precious element! How often, formerly, has periodical pestilence arisen from deficiency of water; and how often has fire devoured whole cities, which a timely supply of water might have saved! Kings have received almost divine honours for constructing aqueducts, to lead the pure streams from the mountains into the peopled towns. In the present day, it is he who has travelled on the sandy plains of Asia or Africa, where wells are more prized than mines of gold, or who has been detained on ship-board, when the supply of fresh water was falling low, who can appreciate fully the blessing of that abundant supply which many now so thoughtlessly enjoy. The writer of this had once, on board ship, to superintend the adaptation to the distillation of water of the cook's great boiler, when, from an accidental leakage, a scarcity was feared.

470. The subject of *fluid level* leads to the consideration of springs or wells, and of the operation of boring for water.

471. The water which falls from the clouds over the land, and which must all ultimately return to the sea, may find its way to the river channels, either by running directly along the surface of soils which refuse it admittance; or by first sinking into porous earth, and then oozing out at lower situations in the form of springs. If a spring be as low as the bottom of the porous earth from which it issues, that is to say, as low as the surface of the impermeable clay or rock on which at some depth all such earth rests, it may drain the whole; but if not, the water will stand at a certain level among the earth as water stands among

bullets in a tub. If a hole or pit be then dug in such earth, to below the level of the water lying there, the pit will soon be filled with water up to the level around, and will be called a well. In many places this water-level is very far below the surface of the ground; and in some places, by reason of the water having an easy drainage from the earth towards the sea, or of the superficial soil being altogether impervious to water, no well is to be found within an accessible depth.

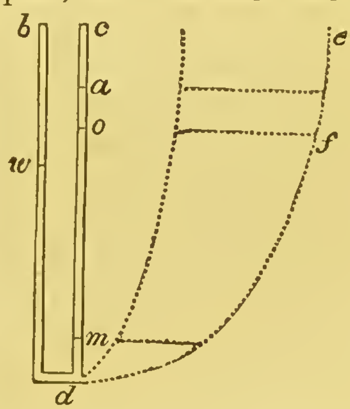
472. A remarkable illustration of this subject occurred some years ago in Kent, on the occasion of cutting between Rochester and Gravesend the canal called then the Thames and Medway Canal, now transformed into a railway. This canal consisted of but one cut or level, about seven miles long, two of which were in a tunnel through the hill. The level was that of high water in the connected rivers; the intention having been to let the canal be filled always from the rivers at high tide:—but as the permanent level of the subterranean water in the surrounding land, and therefore of all the wells of the inhabitants was, as should have been anticipated, half-way between the sea levels of high and low tides, the salt water from the rivers was no sooner admitted to the canal, than it spread into the land on both sides, where the resisting internal water-level was lower, and spoiled all the wells. If the canal had been dug a few feet lower, the evil would not have occurred, and the company would have escaped paying the heavy damages, which rendered their undertaking a very ungainful speculation.

473. All the wells and springs in the world are merely the rain water which has sunk into the earth at higher levels, appearing again, while escaping or drawn at lower outlets: nature thus admirably making the interior of the earth an ever-stored reservoir of a substance indispensable to the existence of man, and other living creatures. It is worthy of remark here, that high cultivation or agricultural improvement of a country has a great effect on the quantity of spring water in it. While the face of a country is rough or uncultivated, the rain water remains long among its inequalities, slowly sinking into the earth to feed the springs, or slowly running away from the surface of bogs and marshes towards the rivers. The rivers hence have a comparatively uniform and regular supply, even when rain has not fallen for a long time—but in a well-drained country, the rain, by the numerous artificial channels, finds its way to the brooks and rivers almost immediately, and produces

often dangerous floods or inundations of the neighbouring low grounds. A friend of the author had a waterfall working a mill in Surrey, which he formerly let at a rent of £1,200 a year; but after agricultural improvements in the district, the supply of water proved generally either excessive or deficient, and the value of the mill was reduced by one-half. The supply at last became so irregular that a steam-engine was substituted for the waterfall.

474. The surface of our globe, as explained hereafter, is formed chiefly of distinct layers of clay, chalk, sand, gravel, &c., originally deposited from water, but afterwards solidified, and in many places upheaved by subterranean agencies into great variety of position. In particular situations these strata have have taken concave shapes, becoming like cups or basins placed one within another. Now as water poured in to occupy the space between two basins so placed would rush through any hole made in the bottom or side of the inner basin, to the height of the water around it, so on boring for water through an interior water-tight stratum or basin of clay, the water often springs out and rises far above the surface of the ground. Such a spring is called an "Artesian well," from having become common in Artois in France. London stands in a hollow depression or basin of clay, placed over chalk which contains water, and on boring through the clay, the water issues, and rises often considerably above the surface of the ground;—showing that there is a higher source or level in the chalk among the hills of Surrey or Middlesex.

475. When fluids of different kinds, and of different weights under the same bulk, are made to oppose, or to balance each other in communicating vessels—as water, for instance, in one leg of the bent tube, *b d c*, and oil in the other —the surfaces will not rest or settle at the same height or level, but that of the lighter fluid will be just as much higher than that of the other as it is lighter. Thus a column of oil must be of a length as *d o*, to balance a shorter column of water *d w:* and alcohol, because lighter than oil, to balance the same water, would have to stand higher still, as at *a;* while mercury, because thirteen times weightier than water bulk for

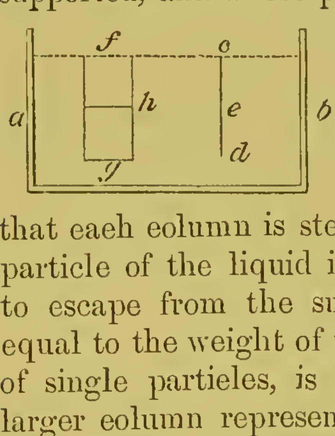


bulk, would stand only about *m*. The shape, size, or position of the vessels in which the opposing fluids might stand, would have no influence on the relative heights of the surfaces (Art. 466). Were a larger vessel, such as is represented here by the dotted lines between the letters *e f m*, to be substituted for the leg *c d* of the tube, the various fluids to balance the water in *b d*, would have to stand just as high in it, as in the smaller tube.

476. "*A body immersed in a fluid, displaces exactly its own bulk of it, which quantity having been just supported by the fluid around, the body is buoyed up with force exactly equal to the weight of the fluid displaced, and must sink or swim according as its own weight is greater or less than this.*" (Read the Analysis.)

477. A bladder, or caoutchouc bag, full of air, and having just the bulk of a pound of water, requires a force of one pound (except a few grains, the weight of the air) to force it under water. The same bulk of gold is pressed upwards in water with exactly the same force; so that, if previously balanced at the end of a weighing beam, it appears on immersion to have lost one pound of its weight. And a piece of wood, ivory, or any other substance, having exactly the same bulk, is opposed on entering the fluid by the same resistance.

478. The reason of this is obvious, for the immersed body takes the place of water which weighed one pound and yet was supported, and whose pressure was necessary for the equilibrium



of the rest. In a vessel of water represented here by the figure *a b*, let us attend to any portion of the water, a single column of particles for instance, represented by the line *c d:* we know that each column is steadily supported in its place, because the particle of the liquid immediately under it is tending upwards to escape from the surrounding pressures, with force exactly equal to the weight of the column; and what is true of a column of single particles, is true of any other portion, such as the larger column represented by the figure *f h g*. If such portion weighed exactly a pound, the surface under it would be tending upwards with the force of a pound; and if the portion, without changing its bulk or form, were to become ice, it would still be exactly supported by the surface below pressing upwards with force of a pound; and further, if a similar column of wood, or

stone, or metal, were there, the surrounding pressures would still be the same. Again, if we suppose only half the column to be solidified, the portion $h\ g$ for instance, it would still be pressed upwards with a force of one pound at g; but its own weight of half a pound, and the weight of the half pound of water above it, and bearing on it, would still produce an exact balance and maintain rest.

It is very important to have clear notions on this subject; and as different minds apprehend such matters with different degrees of facility, and in different ways, we shall state the same general truth in other words.

479. Let us consider a mass of fluid as consisting of a vast number of extremely minute columns of single particles standing side by side, where every particle supports those above it by the tendency upwards which it acquires through the pressure of the fluid below and around it. Then if we suppose the particles of a portion of the fluid mass, of any shape, to stick together, or to become ice without change of bulk or weight, that portion when solid would still be between the same forces as when fluid, and therefore would be equally supported, and would remain at rest. And if gold, or silver, or glass, or wood, having the same bulk, were substituted for the supposed ice, such new substance would still be pressed upwards with the same force; so that a substance of exactly the same weight as the ice or water displaced, would have no tendency either to rise or to fall, more than the water itself had; but a substance heavier would sink, and one lighter would swim, and in either case with force exactly proportioned to the difference between its weight and that of an equal bulk of water.

480. Few persons, in now reading the statement of this truth —in appearance so simple and obvious—would imagine that it could have remained long unknown, and that the discovery of it was accounted one of the most important which human sagacity ever made,—but such is the case. The discoverer was the great Archimedes. He caught the idea one day while his limbs were resting on the liquid support of a bath: and as his penetrating intellect darted into futurity, and perceived many of the important uses to which the knowledge was applicable, he is said to have become so moved with admiration and delight, that he leapt from the water, and, almost uncovered, pursued his way homewards, calling out " ευρηκα, ευρηκα," I have found it.

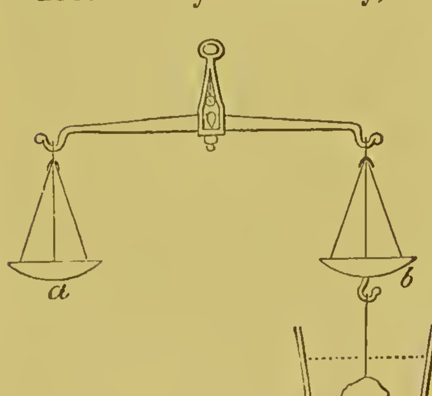
481. The hydrostatic law now explained, has since led to

great advances in very many arts. It gives the ready means of ascertaining in all cases what has since been called the *specific gravity* of bodies, *viz.* the comparative weights of equal bulks of different substances; as of gold, or silver, or copper, or iron, compared with water; and in the case of mixtures, as of gold with silver for instance, of declaring at once the proportion present of each. It may be regarded as a chief foundation of the science of chemistry, for by it the chemist distinguishes one substance from another, distinguishes a pure from an impure substance, and discovers the nature of many mixtures or compounds. The merchant often judges by it of the worth of his merchandize. In any case it enables an inquirer to ascertain at once the exact volume or solid bulk of a mass, however irregular—even of a bundle of twigs. It has become the cause of improvements in navigation, in marine architecture, and so forth.

We proceed now to consider more in detail the subject of *comparative weights or specific gravities.*

> "*The force with which a body immersed in a fluid is pressed or buoyed upwards being exactly as the weight of its bulk of that fluid, by ascertaining this force and comparing it with the weight of the body itself, the comparative weights or SPECIFIC GRAVITIES are found.*" (Read the Analysis, p. 160.)

483. If any solid body, a mass of gold for instance, represented by *c*, in the figure, be suspended by a thread or hair from the bottom of one scale *b* of a weighing-beam, and be balanced by weights put into the other scale *a*, and if then a vessel of water be lifted up under the solid, so that the water shall surround it, the body is pressed or buoyed upwards by the water with force equal to the weight of the water which it displaces; the weights therefore, then required in the scale *b* to overcome the buoyancy or restore the balance, show truly the exact weight of the water displaced; or of water equal in bulk to the body; and the weights in the two opposite scales show the comparative weights of the body and of its bulk



of water. In the case above supposed, whatever weight the gold had in the air, it would seem, when the water surrounded it, to lose nearly a nineteenth part of such weight; that is, the water would support it with this force; and gold would thus be proved to be nearly nineteen times as heavy as water.

Another mode of obtaining with tolerable accuracy the same result, is as follows. To suspend an ascertained weight of any solid substance by a thread, and then to lower it into a vessel full of water. It will cause a bulk of water just equal to its own, to flow over the edge of the vessel. By then weighing the water so displaced, the comparative weights of equal bulks of the two substances are determined.

484. In making a table of specific gravities, it was necessary to select some common standard with which all the other substances should be compared, and this has been done in choosing water; the reasons of preference being, that water can be easily procured in a state of purity, and therefore of uniformity, in all situations. When we say, therefore, that, in round numbers, gold is of the specific gravity 19, we mean that it is just so much heavier than its bulk of pure water in its densest state, *viz.* at the temperature of 40 degrees of Fahrenheit's thermometer.

485. Because the substances in nature differ much as to form and other qualities, corresponding differences have to be made in the manner of ascertaining their specific gravities: the following cases are the most important.

Solid bodies insoluble in water and *heavier* than it, as the metals, &c., are merely suspended by a thread or hair, having nearly the specific gravity of water, to one scale of the *hydrostatic balance* (simply a good weighing-beam with a water-vessel below one of the scales); and the body being first balanced or weighed in the air, and then in water, as already described, the weight and the loss (represented, if the operator chooses, by the weights in the opposite scales), are the weights of equal bulks of the two substances; and by finding, through the simple arithmetical operation of *division*, how often the weight of the water is contained in the weight of the solid, we find the specific gravity of the solid, or how much it is weightier than its bulk of water. It is almost superfluous to remark, that putting weights into the scale *b*, or taking them out of the scale *a*, are equivalent operations. We shall explain afterwards, that for very delicate purposes, bodies must be weighed first in a vacuum

instead of in air, or a suitable allowance must be made; for air itself supports a little any body immersed in it.

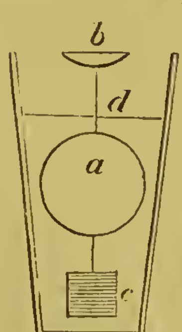
Solids lighter than water,—as cork, are weighed in it by attaching to them a mass of metal or glass heavy enough to sink them, and already balanced in water for the purpose; or by making the line which connects them with the weighing-beam pass under a small pulley fixed at the bottom of the vessel, so that the rising of the end of the beam to which they are attached shall draw them down.

A solid soluble in water,—as a crystal of any salt, may be protected during the operation of weighing in water, by previously dipping it in melted wax, so as to leave a thin covering on it; or it may be weighed in some liquid which does not dissolve it, allowance being afterwards made for the difference between the weight of such liquid and of water.

Powders insoluble in water,—such as gold-dust, are weighed in a glass cup, which has been previously balanced in water for the purpose.

Powders soluble in water—must be weighed in some other liquid.

486. *Other liquids*—may be compared with water, in several ways. 1st. If a phial be made to hold exactly one thousand grains of distilled water, at the temperature of 40°, the weight of the same measure of any other liquid is found, by simply filling the phial, and weighing it. Of sulphuric acid, for instance, such a phial will contain nearly nineteen hundred grains, while of alcohol it will receive only about eight hundred. 2nd. A bulb of glass, which loses one thousand grains when weighed in water (which thousand grains is therefore the weight of its bulk of water), may be weighed in other liquids, and the difference of loss marks the specific gravity, as in the last case. The bulb for this purpose may be of any size, but one which loses in water exactly one thousand grains, is preferable from the simplicity thereby given to the calculations. 3rd. A contrivance which renders the beam and scales altogether unnecessary, is a hollow floating bulb of glass or metal *a*, with a slender stalk rising from it to support the little scale or dish *b*, and with another stalk descending to carry a weight or weights at *c*, which serve as ballast to it. The whole is so adjusted that when displacing 1000 grains, or other known quantity of pure water, it shall float with a certain mark upon the upper stalk



just at the surface of the water. By then immersing it in other liquids, and finding how much weight must be added to or taken from it above or below to make it float in them at the same elevation, the comparative weights of these other liquids and of water are found:—or the difference of weight which makes it float at different elevations in water, having been previously ascertained, it will only be necessary, in any other case, to note exactly its elevation: an inch of the slender stalk may be equivalent to a difference of ten grains. This instrument is called an *hydrometer.* There are generally printed tables and directions accompanying all forms of it, telling the exact import of the several indications, and the allowances to be made for temperature, &c. 4th. The shortest mode of ascertaining the specific gravities of liquids is to have a set or series of small glass bulbs of different known specific gravities, so that when they are thrown into any liquid, those heavier than it will sink, and those lighter will swim, while that one which marks its specific gravity will remain merely suspended. The bulbs must of course be numbered, and the specific gravity of each be previously known.

A common use of hydrometers is to ascertain the quality of the distilled spirits brought to market, as of rum, brandy, gin, &c. All these consist of alcohol more or less diluted with water; and duty or tax is levied upon them in proportion to their strength, or the quantity of alcohol which they contain. A delicate hydrometer discovers this at once.

A shopkeeper in China sold to the purser of a ship, a quantity of distilled spirit according to a sample shown; but, not standing in awe of conscience, he afterwards, in the privacy of his store-house, added a certain quantity of water to each cask. The spirit having been delivered on board, and tried by the hydrometer, was discovered not to agree with the sample. When the vender was charged with the intended fraud, he at first denied it, for he knew of no human means which could have made the discovery; but on the exact quantity of water which had been mixed being specified, a superstitious dread seized him, and having confessed his roguery, he made amends. On the instrument of his detection being afterwards shown to him, he offered a high price for what he foresaw might be turned to great account in his trade.

487. The specific gravity of *aëriform substances* is ascertained by means of a glass flask of known size, furnished with a stop-cock. It is first weighed when emptied by the air-pump, and

afterwards when filled successively with water and with the different airs or gases. Comparison of the weights gives the specific gravities as already described.

488. The following table shows in round numbers the comparative weights or specific gravities of some common substances. Water is the standard kept in view, and any equal bulk of another substance is heavier or lighter than water, according to the numbers severally attached to them.

Water	1	Common Stones	$2\frac{1}{2}$
Platinum	$22\frac{3}{4}$	Common Salt	2
Gold	$19\frac{1}{3}$	Brick	2
Mercury	$13\frac{1}{2}$	Ice	$\frac{9}{10}$
Silver	10	Alcohol	$\frac{8}{10}$
Copper	$8\frac{3}{4}$	Æther	$\frac{3}{4}$
Steel and Iron	8	Cork	$\frac{1}{7}$
Diamond	$3\frac{1}{2}$	Atmospheric Air	$\frac{1}{840}$
Glass	3	Hydrogen Gas	$\frac{1}{12000}$

Complete tables are found in systems or Dictionaries of Chemistry.

A cubic foot of water happens to weigh very nearly one thousand ounces avoirdupois, or $62\frac{1}{2}$ pounds. Hence in the foregoing table, the figures denoting the specific gravities tell how many times a thousand ounces of the different substances a cubic foot contains. Of gold, for instance, a cubic foot contains more than nineteen thousand ounces, being worth in money about £63,000 sterling. A cubic foot of common air contains only a litle more than one ounce; and of hydrogen gas, the lightest of ponderable things, a cubic foot contains less than a drachm.

The following facts also are illustrations of the truth, that a body immersed in a fluid is buoyed up, or has its entrance resisted, with force equal to the weight of the quantity of fluid which it displaces.

489. A stone which on land requires the strength of two men to lift it, may be lifted and carried in water by one man. There are cases, therefore, where the support of water thus rendered useful is equivalent to the assistance of an additional hand. An ignorant person will wonder why he can lift a certain stone to the surface of water, but no farther.

The invention in modern times of the diving-bell and diving-helmet having enabled men, in the building of piers, bridges, &c., to work under water almost as freely as above, many have experience of this supporting influence of water. Some had

supposed the fact accounted for by saying that the denser air of the diving-bell when received into the lungs gave greater strength. In recovering property from a sunken ship by the diving-bell, every object is found to be lighter in the proportion now stated.

This law explains also why stones, gravel, sand, and mud, are so easily moved by waves and currents. People expressed astonishment, in March 1825, on learning that at the Plymouth Breakwater, then in progress of construction, the storm had displaced blocks of stone weighing each many tons; they did not reflect that the moving water had only to overcome about half the weight of the stone.

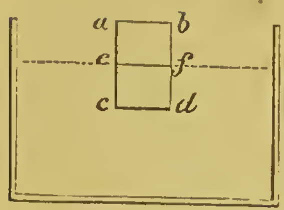
When a person lies in a bath, the limbs are so nearly supported by the water as to require scarcely any exertion on the part of the individual to change their position. When this softest of all beds has been indulged in for half an hour or more, the person, on first lifting a limb out of the water, feels surprise at its great apparent weight. The workers about diving-bells always experience the sensation now spoken of, on returning to the air.

490. The bodies of most fishes are nearly of the specific gravity of water, and therefore, if lying in it without making exertion, they neither sink nor rise in it very quickly. When this subject was less understood, there was a general belief that fishes had no weight in water; and it is related as a joke at the expense of philosophers, that a king, having once proposed to his men of science to explain this extraordinary fact, many profound conjectures were offered, but not one of the competitors thought of trying what really was the fact. It was beneath the dignity of science in those days to make an experiment. At last a simple man balanced a vessel of water in the scale of a weighing beam, and on then putting a fish into the water, found that scale preponderating just as much as if the fish had been weighed in it alone.

In the sense now explained, water is said to have no weight in water. The least force will raise a bucket of water from the bottom of a well to the surface; but if the bucket be then lifted at all farther its weight is felt, just in proportion to the part of it raised above the surface.

"*A body lighter than its bulk of water will float in water, and with force proportioned to the difference.*" (Read the Analysis, p. 160.)

491. The reason of this is elear. If any body, the block of wood $a\ b\ c\ d$ for instance, be held partially immersed in water, we know that the upward pressure of the water on the bottom $c\ d$, is exactly what served to support the water displaced by the block, *viz.*, water of the bulk, $e\ f\ c\ d$. The block, therefore, that it may remain floating out of the water, as far as here represented, must have in its whole volume only the weight of the water which the immersed part of it displaces. If it be lighter than this, it will rise farther; if heavier, it will sink farther, until the exact balance be produced.



Hence of any floating body which weighs a pound displaces just a pound of water, whether the body be very light in proportion to its bulk, as cork, or heavier, as a piece of dense wood. This fact is experimentally shown by putting such bodies in succession to float in a vessel full of water. The water displaced by each will run over the sides of the vessel, and will always weigh just a pound.

Hence an empty porcelain basin weighing a pound will sink in water only so far as a wooden basin or bowl of the same external dimensions and of the same weight; and the weight of either basin may be in the substance of which it is formed, or in anything else put into it as a load.

Hence a boat made of iron, floats just as high out of water as a boat of similar form and size made of wood, provided the iron be proportionally thinner than the wood, and therefore not heavier on the whole. An empty metallic pot or kettle may be seen floating with a great part of it above the surface of the water. Prejudice for a long time prevented iron from being used in the construction of boats and ships, although possessed of many advantages over wood, as is now proved by the general employment of it for such purposes.

Hence a ship carrying a thousand tons of cargo will just draw as much water, or float to the same depth, whether the cargo be of eotton or of lead :—and the exact weight of any ship and eargo may be determined by finding how much water the floating ship displaces. In canal boats, which are generally of a simple form, this truth affords a ready means of ascertaining the quantity of their load.

492. The human body, in an ordinary healthy state with the chest full of air, is lighter than water.

If this truth were generally and practically understood, it would lead to the saving of more lives, in cases of shipwreck and other accidents, than all the mechanical life-preservers which man's ingenuity has yet contrived.

The human body at rest, and with the chest full of air, floats with nearly half the head above the water—having then no more tendency to sink than a wooden log. That a person in water, therefore, may live and breathe, it is necessary only to keep the face uppermost, so that the mouth may be in the air. The reasons that in ordinary accidents so many people are drowned who might easily be saved, are chiefly the following:—

1st. They believe that the body is heavier than water, and therefore that unless continued exertion be made, it must sink. Hence, instead of lying quietly and a little on the back, with the face upwards, and with the face only out of the water, they generally assume the position of a swimmer, in which the face is downwards, and the whole head has to be kept out of the water to allow of breathing. Then, as a man cannot retain this position but by continued exertion, he is exhausting his strength even if a swimmer, and if he cannot swim, the unskilful attempt will scarcely secure for him even a few respirations.

2nd. The body raised for a moment by any exertion above the natural level, sinks as far below that when the exertion ceases; and the plunge, by appearing the commencement of a permanent sinking, terrifies unpractised individuals and renders them easier victims to their fate.

3rd. They fear that water entering by the ears can drown, as if it entered by the nose or mouth, and they make a wasteful exertion of strength to prevent this; the truth being, however, that the water can fill only the outer ear, as far as the membrane of the drum, where its presence is of no consequence. Every diver and swimmer has his ears thus filled with water at every plunge, and suffers not.

4th. Persons unaccustomed to the water, and in danger of being drowned, generally attempt in their struggle to keep their hands above the surface, from feeling as if their hands were imprisoned and useless while below; but this act is most hurtful, because any part of the body held out of the water, in addition to the face which must be out, requires additional effort to support it, which the individual is supposed at the time ill able to afford.

5th. They do not reflect, that when a log of wood or a human

body is floating upright, with a small portion only above the surface, in rough water, as at sea, every wave in passing must cover it completely for a little time, but will again leave its top projecting in the interval. The practised swimmer chooses this interval for breathing.

6th. They do not think of the importance of keeping the chest as full of air as possible; the doing which has nearly the same effect as tying a bladder of air to the neck, and, without other effort, will cause nearly the whole head to remain above the water. If the chest be once emptied, while the face is under water and the person cannot inhale again, the body remains specifically heavier than water, and will sink.

493. To convince a person learning to swim of the natural buoyancy of his body, it has been common to throw an egg into water about five feet deep, and then to desire him to dive and bring it up again. He discovers that instead of his body with the chest full of air naturally sinking towards the egg, he has to *force* his way downwards, and is lifted again by the water as soon as he ceases his effort. A still simpler way of teaching a learner what he needs to know, respecting the floating of the human body in water, is to let a cord be attached to any fixed support above a deep bath, and then to let the bather discover, that by taking the end of the cord in his hand, kept under the water, he can by the gentlest pull raise himself in the water, and that by placing himself with his face turned upwards, his body will float without any aid from the cord, as long as he pleases.

494. When a man dives far, the pressure of deep water compresses, or diminishes the bulk of the air in his chest, so that without losing any of that air, he yet becomes really heavier than water, and would not again rise, but for the exertion of swimming upwards. The author once, during a calm at sea, witnessed the occurrence of a sailor (a strong-bodied West-India negro) falling into the sea from a yard-arm eighty feet high. The velocity on his reaching the water was so great, that he shot deep into it, and, of course, his chest was compressed as now explained: probably also the shock stunned him, for although he was an excellent swimmer, he only moved his arms feebly once or twice, and was then seen for a considerable time afterwards gradually sinking, as a black diminishing speck in the abyss.

It is not necessary that every person should learn to swim; but every one who makes voyages should have practised the easy

lesson of resting in the water with the face out. The head, from the large quantity of bone in it, is a heavy part of the body, yet, owing to its proximity to the chest, which is comparatively light, a little action of adjustment with the hands easily keeps it uppermost. Many of the seventy passengers who were swallowed up on the sudden sinking of the Comet steam-boat near Greenock, in November 1825, might have been saved by the boats which so soon went to their assistance, had they understood what we are now explaining.

A man having to swim far, may occasionally rest on his back for a time, and resume his labour when he is somewhat refreshed.

495. So little is required to keep a swimmer's head above water, that many individuals, altogether unacquainted with what regards swimming or floating, have been saved after shipwreck, by catching hold of broken pieces of wood. An oar will suffice as a support to several people, provided no one of the number attempts by it to keep more than his head out of the water; but often, in cases where it might be thus serviceable, from each person wishing to have as much of the security as possible, the number benefited is much less than it might be.

The most common contrivances, called *life-preservers*, for preventing drowning, are strings of corks put under the chest or neck, or air-tight bags applied round the upper part of the body, and filled when required, by those who wear them blowing into them through valved pipes attached.

On the great rivers of China, where thousands of people find it more convenient to dwell in covered boats, than in houses upon the shore, the younger children have a hollow ball of some light material attached constantly to their necks, so that in their frequent falls overboard, they are not in danger.

Life-boats have a large quantity of cork mixed in their structure, or of air-tight vessels of thin copper or tin plate; so that, even when the boats are filled with water, a considerable part floats above the general surface.

496. Swimming is much easier to quadrupeds than to man, because the ordinary motion of their legs in walking and running is that which best supports them in swimming. Man is at first the most helpless of creatures in water. A horse while swimming can carry his rider with half the body out of the water. Dogs commonly swim well on the first trial.—Swans, geese, and water-fowl in general, owing to the great thickness of

feathers on the under part of their bodies, kept dry by the oil spread upon them, the great volume of their lungs, and the hollowness of their bones, are so bulky and light, that they float upon the water not unlike stately ships, moving themselves about by their webbed feet as oars. A water-fowl floating on plumage half as bulky as its naked body, has about half that body above the surface of the water; and similarly a man reclining on a floating mattress, as in the hydrostatic bed afterwards to be described, has nearly as much of his body above the level of the water-surface, as he forces of the mattress under it. His position therefore depends on the thickness of the mattress.

497. A man walking in deep water may tread upon sharp flints or broken glass with impunity, because his weight is nearly supported by the water.

But many men have been drowned in attempting to wade across the fords of rivers, from forgetting that the body is so nearly supported by the water, that it does not press on the bottom sufficiently to give a sure footing against a very trifling current. A man, therefore, carrying a weight on his head or in his hands held over his head, as a soldier bearing his arms and knapsack, may safely wade across a river, where, without a load, he would be carried down the stream.

There is a mode practised in China of catching wild ducks, which requires that the catcher be well loaded or ballasted. Light grain being first strewed upon the surface of the water to tempt them, a man hides himself in the midst of it, under what seems a gourd or old basket drifting with the stream, and when the flock approaches and surrounds him, he quickly obtains a rich booty by snatching the birds down one by one—adroitly making them disappear as if they were diving, and then securing them below. Each bird becomes as a piece of cork attached to his body.

Fishes can change their specific gravity, by diminishing or increasing the size of the little air-bag contained in their body. It is because this bag is situated towards the under side of the body, that a dead fish floats with that side uppermost.

Animal substances, in undergoing the process of putrefaction, give out much aëriform matter. Hence the bodies of drowned persons remaining in the water, generally swell after a time, and rise to the surface, again to sink when the still increasing quantity of air bursts the containing parts.

498. A floating body sinks to the same depth whether the mass

of fluid surrounding and supporting it be great or small. This is seen when a porcelain basin is placed first in a pond and then in a second basin only so much larger than itself that a few spoonfuls of water suffice to fill up the interval between them. One ounce of water may thus float a thing weighing several pounds, affording an additional instance of the *hydrostatic paradox.* Even if a large ship were received into a dock, or case, so nearly fitting its form that there were only half an inch of interval between it and the walls of the dock, it would float as completely, when the few hogsheads of water required to fill this interval up to its usual water-mark were poured in, as if it were on the high sea. In canal locks, when the boats are made nearly to fit the space on which they have to rise and fall, the expense of water to work the lock is much diminished.

The preceding examples of floating are all illustrations of the truth that the pressure of a fluid on any immersed body is exactly proportioned to the depth and extent of the surface pressed upon. The lateral pressures are opposite and just balance one another, and the upward pressure under the bottom is exactly balanced by the weight of the body above.

499. Similar reasoning to that which proves that the whole weight of a body acts as if it were lodged in the point called its centre of gravity, proves also that the whole buoyancy of a body, or rather the upward push of the fluid in which a body is immersed, acts as if lodged in the point which was the centre of gravity of the fluid displaced. This point consequently is called the "centre of buoyancy."

A floating body, therefore, to be stable in its position, must either have its *centre of gravity* exactly below the *centre of buoyancy*—in which case it resembles a pendulum hanging at rest, or it must have a very broad basis or bearing on the water, so that any inclination must cause the centre of gravity to ascend,—in which latter case it resembles a cradle or rocking-horse.

500. Hence arises, in the stowing of a ship's cargo, the necessity of putting the heavy merchandize low down, and often of putting iron ballast under all the ordinary merchandize. Hence also, comes the danger of having cargo or ballast which is liable to shift its place. A ship loaded entirely with loose stones is sometimes lost by a high wave making it incline for

a moment so much that the load shifts to one side, which will then be kept down. For a similar reason, a cargo of salt or sugar has a peculiar danger attached to it, for if the ship leak, or admit water, part of the cargo may be dissolved and be then pumped out with the bilge water, leaving the ship with altered trim. In a fleet coming home from India in 1809, four fine ships foundered during a hurricane off the Isle of France, and from what happened in the other ships that were saved, the cause of the destruction was judged to have been, that much of the saltpetre of the cargoes had been dissolved and pumped out, so that the ships in consequence became unmanageable.

Bladders used by beginners in swimming are dangerous, unless secured so as not to shift towards the lower part of the body.

A great inventor (in his own estimation) published to the world, that he had solved the important problem of walking safely upon the water; and he invited a crowd to witness his first essay. He stepped boldly upon the yielding surface, equipped in bulky cork boots, the supporting power of which he had previously tested in a butt of water at home; but it soon appeared that he had not considered sufficiently the centres of gravity and of flotation, for in the next minute all that was to be seen of him was a pair of legs projecting upwards, the movements of which showed the owner to be little at his ease. He was released and taken home, with his genius cooled and schooled by the event. Some soldiers one day finding cork *jackets* among old military stores, determined to try them; but mistaking the shoulder-straps for lower fastenings, put them on as trousers, and when they walked in, with the hope of being able to sit pleasantly on the water, their heavy heads went down, and they were nearly drowned.

501. When, on the return of summer, the ice breaks up in polar regions, immense masses of it are set afloat, projecting high into the air and sinking deep into the sea. The melting process may go on so unequally in the water and in the air, as by changing the places of the centres of gravity and flotation to cause the sudden subversion of the iceberg with a tumult in the ocean around, felt at the distance of leagues.

The phenomena of pressure, floating, &c. in fluids, vary in proportion to the weight or specific gravity of the fluid.

502. A ship draws less water, or swims lighter, by about a

thirty-fifth part, in the heavy salt water of the sea than in the fresh water of a river: and for the same reason a man swimming supports himself more easily in the sea than in a river.

Some kinds of wood that float in sea water will sink in that of a river, or which sink in any water will float in oil.

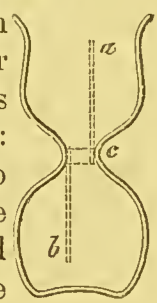
A man floats on mercury as the lightest cork floats on water.

503. Had the water of our ocean been a little heavier than it is, men after shipwreck would have had to think of famine and cold as much as of drowning.

Oil floats on water, but sinks in alcohol or ether. The term *proof spirit* meant spirit light enough for oil to sink in it. The strength of spirit is proportioned to its lightness.

Cream rises in milk, and forms a covering to it.

504. Wine, if slowly and carefully poured on water, will float upon it. In a vessel shaped like a common hour-glass, as here sketched, only with a larger opening at *c* between the two chambers, if wine be put into the under chamber, and water into the upper, the two liquids will gradually, to a considerable extent, change places: and if the lower half of the glass be covered, so as to leave the upper half with the appearance of a simple goblet, the water will seem to have been changed into wine. The liquids are less mixed, and change places sooner, when there is a tube *b* to carry the water down to the bottom without touching the wine, and a tube *a* to carry the wine directly to the top.



Mercury, water, oil, and air may all be shaken together and mixed in the same vessel, but on being then allowed to stand, will separate again and arrange themselves in the order of their specific gravities.

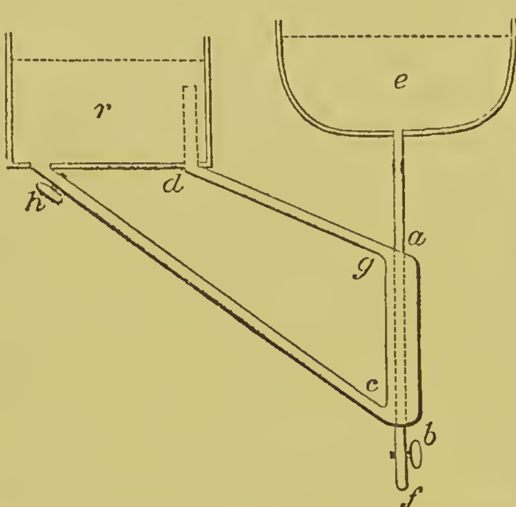
505. When, in a mass of water, part of it is heated more than the rest, that part, by its expansion, becomes specifically lighter than the rest, and takes its place on the surface. Hence, when heat is applied continuously to the bottom of a vessel containing water, as to a boiler placed on a fire, a circulation is established, which goes on from the first moment until the source of heat is removed:—water is always rising from the hotter parts of the vessel, and descending towards the colder parts.

In like manner, when a tall glass containing hot water is dipped into cold water, a downward current takes place within the tall glass near the sides all round, and there is an upward

current in the middle. This motion is rendered very obvious by putting small portions of amber into the water, for these being nearly of the specific gravity of water, rise and descend with it. On account of the currents established in such cases, heat applied to the bottom of a vessel of liquid is soon equally diffused over it; but heat applied at the top is there confined, because the heated and lighter fluid does not descend.

506. The currents in a fluid, produced by local differences of temperature, are important parts of various processes which the author suggested in the first edition of this work by the following paragraph.

507. "Heat may be transferred from one liquid to another, without mixing them, by making the hot liquid descend in a very thin metallic tube, through the cold liquid rising around it in a larger tube. Boiling water from the vessel *e*, for instance, may descend slowly by the small tube *e a b f*, which is surrounded from *a* to *b* by cold water ascending through the tube *c g*. Then, as the temperature of two liquids brought so nearly into contact with each other as in these tubes, will not, after a very short time, differ in any one place more than a few degrees, it follows that the water lately cold, will, on leaving the part of the tube *g*, which is in contact



with the boiling water descending directly from *e*, be nearly boiling, while the water lately hot will, on leaving the tube at *b*, which is in contact with cold water just arrived from *h*, be itself nearly cold: and thus equal quantities of hot and cold water will not have become a double quantity of a medium temperature, but will have made nearly a total exchange of temperatures. The flux of the hot water is to be regulated by a cock *b*, and that of the cold water by a cock *h*. The water in the part of the tube *c g d* rises, because it is hotter and therefore lighter specifically than that in the part *h c*.—The author believes that an apparatus made on this principle, with an arrangement of many thin flat tubes instead of a single large

tube, for the descending fluid, and a spacious case *c g* to contain these and the rising fluid, would be an excellent refrigerator in a distilling apparatus, and for cooling the wort of brewers; or would serve as a means of diminishing the expense of warm baths, by transferring the heat from the water lately used to pure water. In distilling, the *wash* or *low wines* about to enter the still, might be used as the cold condensing fluid to surround the worm or vapour tubes, and thus, without expense, would be heated in its progress to the still. Half the original expense of a great porter brewery is in the construction of the numerous water-tight floors on which the hot wort is thinly spread to cool. The practice of warm bathing, very conducive to health, is less common in this country, because the present expense is so great."

Various practical applications of the principle explained in the preceding paragraph, which have been usefully made since the first publication of this work, are described in the chapter on Heat.

508. It is a general truth in nature, that substances contract in size as they cool. There is, however, in water, a curious exception to this rule, which, operating through the principle of specific gravities, effects most important purposes in the economy of nature. Water contracts only down to the temperature of 40° Fahrenheit, below which, towards 32°, or the freezing point, it goes on dilating again, and as ice is about $\frac{1}{15}$th more bulky than as water. Ice therefore floats on the surface of water, and being a very slow conductor of heat, defends the water underneath from the cold air, and preserves it liquid, and a fit dwelling for the finny tribes, until the return of the mild season. And not only is the extreme of cold thus prevented below, but because very cold water remains floating on the surface of a wintry lake, as cream floats on milk, it preserves underneath that moderate temperature which is required for the fishes, just as very hot water in summer remains uppermost, preserving underneath an agreeable coolness. By the dilatation of very cold water, then, and the formation of ice, nature has secured a winter garb or protection for the inhabited lakes and rivers, as effectual as for terrestrial animals, by the periodical thickening of their wool or fur. Had ice become heavier than water, so that it must have fallen to the bottom, and have left the surface without protection, a deep lake, even in mild European winters, might have been frozen into a solid lifeless mass, which summer suns would

no more have melted than they now do the glaciers of Switzerland. But for this important exception, therefore, to a general law of nature—an exception which many regard with delight as one of the clearest instances of providential interference—not a few of the now most fertile and densely peopled portions of the earth's surface would have remained for ever barren and uninhabited wastes.

PART III.

THE PHENOMENA OF FLUIDS.

SECTION II.—PNEUMATICS.

(Aëriform or Gaseous Fluids.)

ANALYSIS OF THE SECTION.

In aëriform fluids, that is, in such as have their particles held far apart by a mutual repulsion, which yields, however, in proportion to any compressing force applied,—the phenomena are modified by the GREAT LIGHTNESS *and* ELASTICITY *of the fluids, but are still in strict accordance with the general properties of fluids already explained, viz.* PRESSURE EQUAL IN ALL DIRECTIONS—PRESSURE AS THE DEPTH—LEVEL SURFACE, *and* FLUID SUPPORT. *The pressure of air, in all directions, and as the depth, may be studied in the effects of the atmosphere, as pressing* on solids—on liquids :—*or when, in conjunction with heat, it produces the phenomena of* boiling, evaporation, clouds, rain, dew, &c.; *or when, by varying in degree, it causes certain substances to exist sometimes in the* liquid *and sometimes in the* aëriform *states. The fluid support in air is exemplified by* balloons, *the* ascent of flame *and* smoke, winds, *&c.*

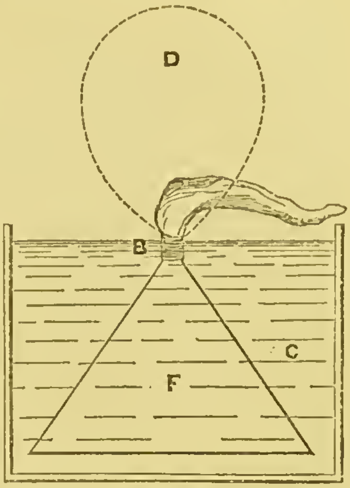
509. VAST is the change which has taken place in the degree of man's knowledge of nature, since philosophers thought that air was one of four primary elements, viz. *air, fire, water*, and *earth*, of which all things were composed, and each of which was for ever distinct from the others. It is now known that air or gas is merely an accidental state, in which any substance may exist, according to the quantity of heat pervading it: the mass being solid when the absence of heat allows its atoms to obey freely their mutual attraction, and to cohere—as in ice, for instance; being liquid, when so much heat is present as nearly to balance the attraction, and to let the particles slide freely among one another—as they do in water; and being aëriform when still more heat is added, causing the particles mutually to repel and dart asunder to a great distance—as they do in steam.

But in any one of these three states, the various substances are as much themselves as in the others, and at the command of the chemist will assume any of the forms which he chooses. As the different substances in nature have different relations to heat, there are some which, at the medium temperature of our earth, are solid, some which are liquid, and some aëriform. The solids, in general, are the heaviest under a given volume, and therefore sink down and form the solid mass or crust of the earth; the liquids follow next in order, and float upon this solid part, filling up its inequalities with a level surface, so as to constitute the watery ocean; while the airs are the lightest of all, and as a second lighter ocean, rest above the sea and above the highest mountains, to an elevation of about fifty miles. Among the substances whose relation to heat causes them, when not restrained in certain combinations, to assume the form of air at very low temperatures, there are two in particular, viz. *oxygen* and *nitrogen*, which are very abundant in nature in such uncombined state, and of these, therefore, the atmosphere chiefly consists; but smaller portions of almost every other substance are found in it. Water, among the supplementary matters, is much more abundant than any of the others; and in its various states of cloud, rain, dew, snow, and ice, it answers a thousand useful purposes, and serves beautifully to diversify the scenes of nature. The atmosphere is about fifty miles high or deep, and therefore, in relation to the bulk of the earth, is as a covering of one-tenth of an inch in thickness to a common library globe of a foot in diameter.

The atmospheric ocean is the great laboratory in which most of the actions of life go on, and on the composition of which they depend. A human being requires for breathing the oxygen of a gallon of fresh air every minute, dying equally if deprived of air, or if confined to the same. All other animals also require oxygen, but in various proportions. And in the vegetable creation, the beautiful green leaf and delicate flower are merely broad and tender expansions of surface for the contact of the vivifying air. Animals give out to the atmosphere a substance which vegetables absorb, and vegetables, by the absorption, fit the air again for the use of animals; so that, upon the whole, in the various changes of nature, there is a perfect balancing of actions, which preserves the atmospheric mass in a uniform state, constantly fit for its various purposes.

510. The materiality of air, or its being a substance occupy-

ing space, is strikingly proved to the common mind by the simple apparatus here sketched. It consists of a common glass funnel F, of known capacity, on the stalk of which, B, the mouth of an empty bag or bladder, C, of the same capacity is tied. If the funnel, with its mouth downwards, be then gradually lowered into water, the water will rise into and fill it up to the neck B; but by the same act the bag will be blown full of the air which before the experiment was in the apparently empty funnel, and will assume the appearance shown by the dotted outline B D. If the full bag be then squeezed, the air in it will be forced down again into the funnel, and will drive out the water which had entered there. The experiment may be repeated any number of times without a particle of the air being lost.



511. While the ancients had that notion of air, which made them apply to it vaguely, and almost indifferently, the names of *air*, *ether*, *spirit*, *breath*, *life*, &c., they never dreamt of making experiments upon it, with a view to prove its close relation to common matter:—and one of the most beautiful portions of the modern history of man's progress in knowledge, is that which tells of the light gradually breaking in upon this most interesting subject. Galileo was the first inquirer led to conclude that air made a definite pressure upon things at the surface of the earth—as in forcing water into the exhausted barrel of a common pump; Torricelli and Pascal proved that this was occasioned by its weight, and hence moreover they estimated the height of the aërial ocean; Priestly, Black, Lavoisier, and others discovered that air was of different kinds, of which one kind, called oxygen, could be united with a metal, so as to increase its bulk and weight, and to produce a compound of totally new qualities; and they showed that many of the metallic ores obtained from mines are merely metals concealed, by being thus united with a substance, which when separated from them ascends as one of the ingredients of the atmosphere. They at last analysed the atmosphere itself, and exhibited its two great ingredients as distinct substances. And since persons still living were born, the nature of air or gas has

been so thoroughly investigated, that we can now take quantities of light, invisible, impalpable fluids like what we breathe, and by strongly compressing and strongly cooling them, can cause their particles to collapse from their aëriform distances to assume the state of a tranquil liquid, or even of a solid, nearly as we take a known quantity of steam and condense it, first to the form of water, and then to the form of ice.

512. The suspicion once excited, that air was as much a material fluid as water, only much less dense, by reason of a greater separation and repulsion of the particles, it was easy to follow out the parallel, and to confirm the supposition by reference to very familiar facts. Thus,—as a leathern sack or pouch, when opened out under the surface of water becomes full, and if its mouth be then tied, retains the water, so that its sides cannot afterwards be pressed together: in like manner a sack or bladder, opened out, in air, and then closed, is found to remain, in a corresponding way, bulky and resisting, and forms what is called an air-pillow.—The motion of a flat board is resisted in water: the motion of a fan is resisted in the air.—Masses of wood, sand, and pebbles, are rolled along or floated by currents of water: chaff, feathers, and even rooted trees, are swept away by currents of air.—There are mills driven by water; and there are mills driven by the wind.—Oil set free under the surface of water, or placed there in a bladder, is buoyed up to the surface: hot air or hydrogen gas placed in a balloon, is buoyed up in the air.—A fish moves itself by its fins and tail in water: a bird moves and directs itself by its wings and tail in the air,—and as on taking the water from a vessel in which a fish swims, the creature falls to the bottom, gasps a few moments, and dies; so, on exhausting the air from a vessel in which birds or butterflies are enclosed, their useless wings may flap; but they sink to the bottom, and if the cruel experiment be continued, they soon become motionless and for ever.

We proceed now to explain that air or gas, as a fluid, differs from the other fluids which we call liquids, chiefly in the two particulars of great lightness or rarity, and of being very extensively elastic, that is to say, the particles being so related, that pressure made brings them much more nearly into contact, and pressure ceasing, allows them to regain their former distances.

Lightness of Air.

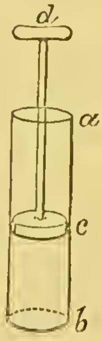
513. The lightness or rarity of atmospheric air, as it exists

near the general surface of the earth, is such, that if, by the action of a pump, a bag holding a cubic foot of it, be emptied into the copper ball of an air-gun, the ball weighs nearly an ounce and a quarter more than before. The same bulk of water weighs nearly a thousand ounces; so that common air is above eight hundred times lighter than water. Other gases, or substances in the aëriform state, have their different specific gravities, just as the same substances have when liquid or solid. Thus water in the form of air, that is to say, when existing as steam, and of the common density, is little more than half as heavy as the same bulk of common air: hydrogen is only one-fourteenth part as heavy: and carbonic acid gas, which is the air that rises out of soda-water, brisk ale, champagne wine, &c., is so much heavier, that even in the atmosphere, it may be poured out of one open vessel into another, as a liquid may be, or, more exactly, as water might be poured out under oil.

Elasticity of Air.

514. A small bladder full of air may be pressed or squeezed between the hands so as to be much reduced in size, but on being relieved from the pressure it immediately regains its former bulk.

515. If a metallic tube or barrel of perfectly uniform bore *a*, *b*, be fitted with a moveable plug or piston *c*, which is covered with leather and oiled, so as to slide up and down without allowing the air to pass by its sides, the air between the piston and the close bottom *b* may be compressed to a hundredth or less of its usual bulk; but when allowed, will push the piston back again with the same force as it opposed to the condensation, and will recover the volume which it had before the experiment.



Again, if the plug at the commencement of the experiment were only an inch from the bottom, enclosing air of the usual density, on drawing it up to the top, the inch of air beneath it would expand so as to occupy the whole tube, having become, of course, proportionally less dense.

516. To the question why the air, which admits of such various density, is found to have that certain degree of density met with at the surface of the earth, we answer, that as the water, in any place near the bottom of the ocean, is pressed with force exactly proportioned to the quantity of water above it, so the

air at the surface of the earth bears the pressure of the superincumbent mass of air, and, on account of its extensive elasticity, suffers, like the lowermost bags of cotton or wool in a great heap, that degree of compression which the superincumbent mass is calculated to produce. We shall see below that the density of the air near the earth varies with certain circumstances which affect the weight of the atmosphere above, as winds, clouds, rain, &c., and that it bears relation to the height of the place of observation above the level of the sea.

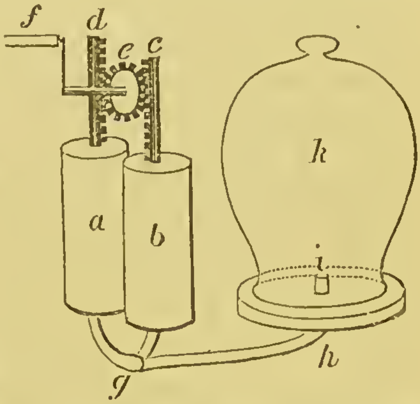
The tube with its piston, described in the last page, becomes, according to the position of valves, either a forcing syringe for injecting and condensing air in a vessel, or what is called a sucking pump for exhausting or removing air from a vessel; both operations depending on the elasticity of the air.

517. That useful contrivance, *a valve*, for whatever purpose used, is in principle merely a moveable flap, or little door, *a*, hinged on an opening, *b*, against which it is held by its weight, or other gentle force. Such a flap, it is evident, will allow fluid to pass only in one direction, *viz.* outwards from the opening, for any fluid tending inwards must shut the flap. The flap of a common bellows is a familiar example.

518. A barrel and piston is a *condensing syringe*, when, in a passage of communication between the bottom of the syringe and a receiving vessel, there is a flap or *valve* allowing air to pass towards the receiver but not to return. The piston, therefore, at each stroke forces what the barrel contains of air into the receiver. When the piston is lifted again after the stroke, air re-enters the barrel from the atmosphere, either through a valve in the piston itself, or through a small hole near the top of the barrel. A second and succeeding downward strokes send each a like measure of air into the receiver, until the desired quantity be accumulated.

519. To convert a forcing syringe or pump into an exhausting syringe or pump, commonly called an *air-pump*, it is necessary only to reverse the position of the valves; then, on the descent of the piston, all the air between it and the bottom of the barrel, instead of entering the vessel or receiver, as in the last case, escapes by a valve in the piston itself towards the atmosphere, and, on the rising of the piston, a perfect vacuum would be left

under it, but that the valve below, in the passage from the receiver, being then opened by the elasticity of the air in the receiver, allows a part of that air to follow the piston. Thus, at each stroke, a quantity of the air, proportioned to the size of the barrel, is removed from the receiver. In an ordinary air-pump there are two similar pumping barrels, as *a* and *b*, to quicken the operation of exhausting; and both are worked at the same time by the reciprocating winch or handle *f*, of which the pinion *e* acts on the teeth of the piston rods *d* and *c*. This double construction has the farther advantage, that the atmospheric pressure, of fifteen pounds per square inch on the upper surface of either piston, and which for a single piston would have to be overcome by the worker in lifting it, is here balanced always by the corresponding pressure on the other piston. Both pumps draw from a tube *g h*, which at *h* rises with air-tight closeness through the round plate or table of the machine to *i*. This flat plate is so smooth, that the glass bell or *receiver k*, with an equally smooth ground lip, when placed upon it, forms an air-tight joining. On working the pump, such a bell is exhausted of its air, and fitted for showing the many interesting phenomena which the air-pump can display,—and which we now proceed to review. To avoid confusion the supporting framework of the pump is not shown here.



520. The law of elasticity of air is, that its outward spring, or resistance to compression, increases exactly with its density, or the quantity of it collected in a given space. Hence, by finding in any case either the density of the air, or the spring, or the compressing force, we know all the three.

521. It has been ascertained by experiments described a few pages hence, that in the atmospheric ocean surrounding the earth, there are nearly fifteen pounds of air above every square inch of the surface of the earth; and that the air nearest the earth, and bearing this superincumbent weight or pressure, has the density evidenced by an ounce and a quarter of weight to a

cubic foot of volume. We further find that such air is reduced to half its bulk, or becomes of what is called double atmospheric density, by an additional pressure of fifteen pounds on the inch, and of triple density by triple pressure, and so forth; and on the other hand, that it dilates to double bulk if the pressure be diminished to half, and to any greater bulk, even beyond a thousand-fold, if the pressure be diminished in the corresponding degree; and that any air bearing a given force or pressure, is always acting as a spring of that force on the surface of whatever it touches.

522. It is very important to be familiar with this truth or law, for it holds with respect to all aëriform fluids as well as common air, and throws light, therefore, on the action of steam-engines, air-guns, and pneumatic machines generally. It also explains the condition of our atmosphere as to density at various elevations; telling us, for instance, that when a balloon has risen through half of the atmospherical mass, the air around and within it is of only half the density which exists at the surface of the earth; and therefore, that a balloon which is only half full when leaving the earth, becomes quite full at such elevation as here supposed.

523. We know not exactly to what extent the rarefaction of air may go on the removal of pressure; in other words, at what distance the gravity of the particles becomes just a balance to their mutual repulsion; and therefore we know not exactly what the degree of rarity is at the top of our atmosphere; but we know that it must be exceedingly great, from the fact that the air left in the receiver of an air-pump has still spring or elasticity enough to lift the valve of the pump, when less remains than the thousandth part of the original quantity. In the most perfect air-pumps, that the exhaustion may be as complete as possible, the machine itself is made to raise the valve.

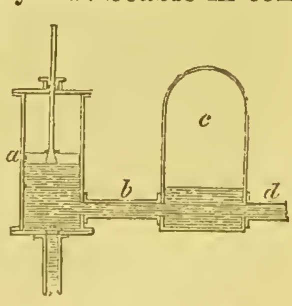
524. The expansion of air is well illustrated by placing a bladder, having a very little air in it, within the receiver of an air-pump. On exhausting the receiver, the bladder gradually swells, with force sufficient to lift a moderate weight laid upon it, and at last appears quite full, and may even burst. A shrivelled apple treated in the same way becomes plump. The explanation of such phenomena is, that at first the air in the bladder or apple is in a state of condensation, like all air near the surface of the earth under the pressure of the superincumbent atmosphere; but that its volume increases as that pressure

is diminished by means of the air-pump:—it is rarefied in the same proportion as the air which remains in the receiver surrounding it.

525. The curious instrument called the air-gun is a gun having a strong globular vessel of copper attached under the lock, into which air is injected by a forcing syringe to be thirty or forty times as dense as the air in the atmosphere around; hence the pressure or elasticity tending outwards is thirty or forty times fifteen pounds on the inch, and when the confining valve is opened for an instant by the action of the lock, a portion of the air escapes into the barrel and propels the charge with the force stated. The effect of air thus condensed nearly equals that of gunpowder, and one charge of the globe suffices for many shots, the force becoming less, however, after every successive discharge.

526. If a bottle or vessel *a b*, partly filled with water, have a tube *c d* passed tightly through its cork to near the bottom of the water; and if more air be then forced through this tube in any way, so as to accumulate in the upper part of the vessel above the water surface *a b*; on turning the cock *c*, which opens the tube, the elasticity of the condensed air will press the water out as a beautiful jet, to a height proportioned to the condensation, and gradually diminishing as the condensation diminishes. Or if such a vessel, with air of common density, be placed under a tall air-pump receiver, on working the pump so as to diminish the density of the air in the receiver, the jet of water will equally rise.—A form of table-lamp, by the force of condensed air, is supplied with oil from a reservoir far below the wick.

527. The elasticity of air is rendered very serviceable in connection with great water-pumps, such as those used for the supply of cities. A pump throws its water not continuously, but by a distinct gush at each stroke, although the current through the pipe towards the city should be uniform. Now uniformity is attained by causing the gushes from the pump *a* to enter by the passage *b* into a large vessel *c*, of which the upper part is full



of condensed air, and from the other side of which, at *d*, the water issues on its way. The air in this vessel (called the *air-vessel*) is then condensed by the entering water, and its resisting spring or elasticity, both immediately, and afterwards during the interval of the strokes, forces the water along the pipe *d*. Each entering gush has the effect of compressing the air a little more for the time, while the flow in the great pipe continues nearly uniform. Such a pump is itself made to take in a little air at each stroke, so that not only is the air-vessel always supplied, but some air is constantly passing on with the water, and effecting the highly useful purpose of giving an elasticity to the whole contents of the pipe and its ramifications.

The same object is attained by the same means in the common fire-engine used to check conflagration. In that engine there are generally several water-pumps working together, which throw their gushes into the air-vessel, from whence it passes in a nearly uniform jet to the point desired.

528. The compressibility and corresponding spring of air are remarkably exhibited in that admirable contrivance of modern times, the *diving-bell*, in which men can descend with safety to considerable depths in the ocean, for the attainment of many objects of high importance to them:—they recover sunken treasures,—they can do ship-repairs at anchor which formerly were possible only in great docks,—they are enabled to pursue works of submarine architecture, as in the construction of lighthouses and harbour walls where formerly no secure foundations could have been laid, and so forth. It is a striking reflection that by acquiring knowledge of the nature of air man can now live and work fathoms deep in the sea, and can ascend for various purposes, miles above the clouds.

529. The diving-bell is a large heavy open-mouthed vessel, with accommodation in it for one or more persons. It is let down into the water with its mouth undermost, from a fit projecting support placed either on the land or on the deck of a vessel. On first entering the water it appears full of air; but air being compressible according to the law above explained, and the pressure of water around the descending bell increasing with the depth, the volume of the contained air gradually diminishes, and at thirty-four feet is reduced to half. The bell then, unless more air were supplied, would of course be half full of water, and a person breathing in it, at each inspiration would receive twice as much air into the lungs as when breathing above

the surface. A constant supply of fresh air is sent down to the bell by a foreing-pump; and the heated and contaminated air, which has served for respiration, and which rises to the top of the bell, may be allowed to eseape by a tube deseending on the outside. The men who work at a distanee from the bell have tubes of eommunieation with it, by whieh they inhale the air required; and they allow the used air to rise away through the water above them. A man eannot breathe easily by sueh a tube if he be either above or below the level of the water in the bell: for if above, the air in the bell is more eompressed than in his chest, and is forced towards him so as to require an effort to resist its admission; and if below, his ehest is bearing greater pressure than the air in the bell, and he must therefore aet strongly with the muscles of the ribs to draw the air down to him. A simple phenomenon explaining this is exhibited when two bladders of air are eonnected by a long tube, and immersed in water to unequal depths: the air is always strongly foreed from the lower one into the upper, beeause the lower one is more eompressed. The diffieulty of pumping air down to the diving-bell inereases, of course, with the depth to whieh it has descended. If the water be pressing on the air in the bell with a foree of fifteen pounds per ineh (whieh happens at the depth of thirty-four feet), it is evident that a syringe or pump eannot injeet more air unless it act with a force greater than this.

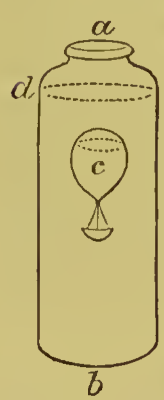
530. Instead of the large diving-bell at first employed it is now found preferable in many cases to have merely a dress for the person, of impermeable eloth, eonnected with a small bell or helmet covering the head and faee, whieh is kept supplied with fresh air by a foreing-pump working eonstantly above the water-surfaee. The diver with this dress ean move about mueh more freely than when in eonneetion with the great bell, for he is not limited to one level, as is explained above.

531. It might be a useful part of the apparatus provided to aid in the recovery of drowning persons, to have always ready for an emergency a eask or other vessel of moderate capacity (say a eubic foot), containing pure air, and made heavy enough just to sink in water, with a breathing tube from it like that of a diving-bell. This would be a provision of air for a man below water for a few minutes; and a man laying hold of it, might instantly descend from a boat, or walk from the shore, into water of moderate depth, to reeover the body of a person lately sunk, and in time probably to save the life, whieh a few minutes

wasted in waiting or in unsuccessful dragging would suffer to be lost. Such an aid might be useful also to pearl-fishers, or to persons who gain their bread by diving to recover things dropped overboard in harbours or anchoring stations; all of whom have hitherto been limited to the single gulp of air taken on descending.

It may be observed that the purposes served by the apparatus just described might be multiplied by placing the air-barrel on wheels, or on a carriage like the now common *perambulator.* With this, the diver might enter from a sloping bank or shore in any direction, to walk about in his search, and, if provided with a pair of spectacles having very convex lenses, he would be able to see under water as distinctly as a fish does. While he might at leisure attach any other object found to his carriage, he could instantly send up for treatment above, the body of a drowning person, by affixing to the head a string of corks or a bag of air, kept loosely hooked to the top of the barrel for the purpose. Such a bag of air might receive from the breathing-tube all the air used by the diver, passing through a branch tube connected with the valved mouth-piece. That air-bag would maintain the specific gravity of the whole apparatus nearly the same during the whole proceeding.

532. There is an exceedingly beautiful philosophical toy, of which the action depends chiefly on the elasticity of air; and which, as it moreover illustrates most of the laws of fluidity, is deemed worthy of description here. It is a miniature balloon or thin globe of glass *c*, having an opening at the bottom, and a little car or basket with an aëronaut hanging to it. If put to float in water while the globe contains air only, it is so light that half the globe remains above the surface; but water may be introduced to adjust the specific gravity of the whole, so that it shall float with only a small portion above the water surface.



If the balloon be then placed in a tall jar of water *a b*, the mouth of which is covered by bladder-skin or india-rubber tied air-tight upon it, on pressing such covering with the hand, the balloon will immediately descend in the water: it will rise again when the pressure ceases, and will float about, rising, or falling, or standing still, according to the pressure made. The explanation of this is, that pressure made on the top of the jar first condenses the air between the cover and the water surface; this

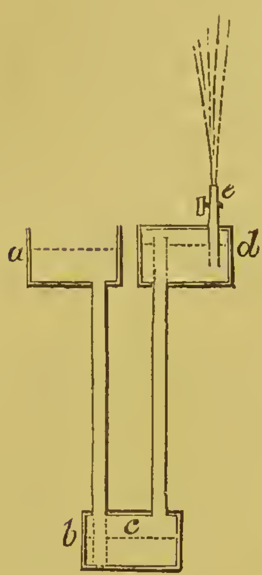
condensation then presses upon the water surface below, and by influencing the water through its whole extent, forces as much more water into the globe as to render the balloon heavier than water, and therefore heavy enough to sink. The air within the globe being thus compressed, repels, as soon as the pressure ceases, the lately entered water, and the balloon becoming, as before, lighter than water, ascends to the top.—If the balloon be adjusted to have a specific gravity too nearly that of water, it will not rise of itself after once reaching the bottom, because the pressure of the depth of water then above it will perpetuate the condensation of the air which caused it to descend. It may even then, however, be made to rise again by inclining the water-jar to one side, so that the perpendicular height of water over it shall be diminished.

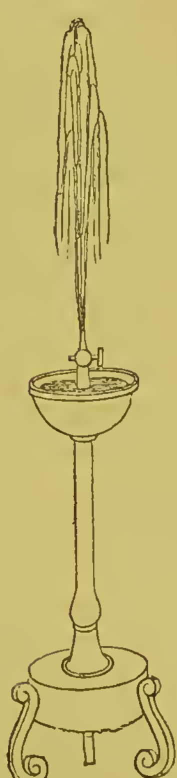
This toy proves many things. 1st, the *materiality* of air, by the pressure of the hand on the top being communicated to the water below through the invisible air in the upper part of the jar. 2nd, the *compressibility* of air, by what happens in the globe just before it descends. 3rd, the *elastic force* of air, shown in the expansion which occurs on the pressure ceasing, as the water is again expelled from the globe. 4th, the *lightness* of air, in the buoyancy of the globe. 5th, it shows that in a fluid *the pressure is in all directions*, because the effects happen in whatever position the jar is held. 6th, it shows that *pressure is as the depth*, because less pressure of the hand is required the farther that the globe has descended in the water. 7th, and it exemplifies many circumstances of *fluid support*. A young person, therefore, familiar with this toy, has learned the leading truths of hydrostatics and pneumatics, and has had amusement as well as valuable instruction.

533. On the same principle as the balloon now described, several little figures of men may be formed of glass, hollow within to contain air, and having each a minute opening at the heel, by which water may pass in or out. If these be placed in a jar as the balloon above described, and be adjusted by the quantity of water admitted into them, so that, in specific gravity, they shall differ a little from each other, and if then a gradually increased pressure be made on the cover of the jar, the heaviest figure will descend first, and the others will follow in succession; and they will stop or return to the surface in reverse order when the pressure varies. A person while exhibiting these figures to spectators who do not understand them, may appear only care-

lessly to be resting his hand on the cover of the jar, although really making the required pressures, and he will seem to have the power of ordering the movements of the mannikins by his will.

534. The ingenious fountain, called the fountain of Hero, by





which water is made to spout far above its source, depends for its action upon the resisting elasticity of compressed air. The vessel *d* is first filled with water, while *b* and *a* contain air only. On then pouring water into *a*, the water of *d* darts upwards through the jet-pipe *e*, to an elevation nearly equal to the length of the tube from *a* to *b*. The reason is, that the water from *a* descends by the tube to *b*, and compresses the air in *c*; which compression conveyed along the other tube from *c* to *d*, acts on the water in the vessel *d*, and causes it to jet upwards. As the pressure is produced by the column of water *a b*, the jet is proportioned to the length of that column.—This kind of fountain may have its parts concealed under a variety of forms, as exemplified in the second figure, and may thus become a pleasing ornament among flowers in a summer drawing-room. It may be made of size to play for an hour or more, and it will always recommence on the water being shifted from the low to the high reservoir. The water which jets from the vessel *d* when caused to fall into the vessel *a*, feeds the compressing column *a b*. A useful table-lamp, appearing a simple column, is constructed on the principle of a Hero's fountain.

Having now explained the two great peculiarities which distinguish aëriform from other fluids, *viz.*, their *lightness* and extensive *elasticity*, we proceed to show that aëriform fluids have the four other properties already described under hydrostatics, as belonging to fluids generally: and first,

"Pressure in all directions." (Read the Analyses at pages 160 and 203.)

535. A quantity of air or gas shut up in any vessel and compressed, is equally affected throughout, and its tendency to escape from the pressure is equal in all directions, as is proved by the force necessary to keep similar valves close wherever placed. Hence the hydrostatic press and hydrostatic bellows described in last section, which depend for their action on this law, may be worked by air or gas as by a liquid.

Owing to this law, air, when allowed, will always rush from where there is more pressure to where there is less. The actions of the common fire-bellows, and of the animal chest in breathing, blowing, sucking, &c., are so many instances.

536. The suddenness with which compression made on one part of a confined aëriform fluid is communicated through the whole, is strikingly seen in the simultaneous increase or burst of all the gas-lights over an extensive building, or even in a long street, at any instant when the force supplying the gas is augmented.

Many very interesting illustrations of the fluid pressure of air being in all directions will occur under the next head, joined with proofs of the atmospheric pressure being as the depth.

"Pressure as the depth."

537. On first approaching this subject, a person is naturally surprised to hear the depth or height of the atmosphere spoken of as something perfectly ascertained, although nobody can ever have mounted to the surface to measure it; but science often furnishes means of reaching precise truth, in cases where ignorance would not dream of the possibility of even an approximation. It may facilitate the apprehension of this point as regards air, to describe, first, a parallel case in which water is concerned.

538. The bottom of a lake evidently supports all the water in the lake, and each portion bears just the weight of the water directly over it: a means then of ascertaining the weight or pressure of water on any portion of the bottom, would tell how much water stood over that portion, and by the known relation of the weight and bulk of water, would tell also the depth at that part. In like manner, the ocean of air which surrounds the globe rests with its whole weight upon the surface of the globe,

and each portion of the surface bears its share: if we ascertain then the pressure of the atmosphere on a given extent of surface, as described below, we find how much air is standing directly over it; in other words, the weight of a column of air resting on such surface as its base, and reaching to the top of the atmosphere. Having then the weight of the whole column, and finding the weight of a given bulk of it at the bottom (ascertained as described in Art. 513), and knowing the law of aërial elasticity (explained in Art. 520), we determine the depth or height of the column by a simple calculation. Now, accurate experiments show that there are nearly fifteen pounds of air over every square inch of the earth's surface; producing the same pressure over the whole surface of the earth as would be made by a depth of water of thirty-four feet, or by a depth of quicksilver of thirty inches; and from this fact, and the ascertained lightness and elasticity of air, we know that its depth on earth must be nearly fifty miles, which, as already stated, is about as much in relation to the size of the earth as a tenth of an inch is to a globe of one foot diameter. The remaining part of this section has chiefly to trace the effects of this mass of matter resting upon the earth's surface, and as a fluid embracing and compressing every object placed there.

539. Water is a substance much more obvious to the human senses than air, and which is constantly under observation; yet many of its most important agencies escape the notice of common observers. Few persons, for instance, of themselves discover the law explained in the last section, of the pressure in water being proportioned to the depth: but when made to observe that a piece of cork plunged deep into it is compressed to much smaller bulk, not only above and below but equally all round, and that strong empty vessels of glass, or even of metal, under the same circumstances, are by the pressure around them crushed or broken inwards, and that pieces of sunken wood at great depths are filled with water through all their pores, so as to become heavier than water, &c., their minds are roused to a sense of the important fact, that within a fluid there is pressure everywhere in proportion to the depth. If the truths of hydrostatics thus long escaped notice, we need not wonder that those of pneumatics escaped still longer.

540. If a piece of bladder-skin or a pane of glass be lying at the bottom of a cistern holding water, the bladder or the glass exhibits no sign of being pressed upon, although it bears on its

upper side the whole weight of the water directly above it; the reason being, that the film of water beneath the bladder resists just as strongly as the water above it presses, in the same way that one brick in a pile resists the weight of the bricks above it. But if the bladder be tied closely over the mouth of a common drinking-glass filled with water, which glass is then placed at the bottom of the cistern, and if, by means of a syringe or pump, the water be extracted from within the glass, the bladder itself has to bear the whole pressure of the water above it (as well as a pressure of the air above the water, to be explained afterwards), and will be torn or burst. The degree of pressure, indicating the depth of water, might be ascertained by placing some support, of which the action could be measured, under the bladder, to sustain it after the removal of the interior water. Now this experiment may be closely copied in relation to our atmosphere or sea of air. An open glass standing on a table, and in common apprehension deemed empty, is really immersed in the fluid air, and is full of it, as the other glass was full of water. Its mouth may be covered over with bladder, and no external pressure will be apparent, because there is a resistance of the air within, just equal to the pressure of the air on the outside:—but if air be then extracted from under the covering, by means of an air-pump, the bladder is first seen sinking down and becoming hollow from the weight of the air over it, and at last bursting inwards with a great noise or crack. By placing a circular piece of wood under the bladder-skin, for it to rest on, and a steel spring of known force to support the wood, we may ascertain very nearly the weight and pressure of the air over it. This mode, however, of ascertaining the weight of the atmosphere, is not that commonly used, but is described here as a readily conceived illustration of the present subject. The problem is solved much more elegantly and completely by means of the barometer described farther on.

The phenomenon of atmospheric pressure is well exhibited by placing the palm of the hand on the mouth of a glass so as to cover it closely, and then extracting the air from underneath the hand: the weight of the atmosphere holds the hand down upon the mouth of the glass with a force soon becoming painful.

As should follow, from the pressure of fifteen pounds per inch detected at the surface of the earth being due altogether to the weight of the superincumbent atmosphere, we find that exactly as a person rises from the earth, as in ascending a hill, and

leaves part of the atmosphere beneath him, the pressure diminishes.—This fact, indeed, now furnishes the readiest means of ascertaining the height of mountains and of balloon ascents, as will be explained in considering the barometer.

541. After the many explanations given under hydrostatics, of fluid pressure being a compression acting equally in all directions, it is almost superfluous to remark, that the downward weight of the atmosphere becomes such a compression. This is exemplified in the fact of the bladder-skin which closes the mouth of a vessel as described above, being as readily burst if turned sideways as if held directly upwards. Every body or substance, therefore, on the surface of the earth, dead or living, solid or fluid, is compressed with this force. In general the pressure on one side of a body is just balanced by the equal pressure on the other, so that no sensible effect follows; and it is on this account that philosophers were so long in discovering it at all, and that half-informed persons are still disposed to doubt its existence; but the proofs offered on all sides to the now awakened attention of inquirers are irresistible. We shall first speak of

"*Atmospheric pressure on solids.*"

542. Because the atmospheric pressure acts equally on the whole surface of any body immersed in the air, if that pressure be in any way prevented from acting on some portion of one side while it continues to act on the counterbalancing extent on the other side, the whole of the latter pressure becomes immediately manifest. This is simply but strikingly illustrated by placing two full-sized bottle-corks together, end to end, so as to expel the air from between them, and then preventing the air from re-entering there by tying over the joining a short piece of caoutchouc tube. If one cork be then seized and raised, the other cork will not only accompany it, as if strongly glued to it, but if the touching surface has an area of an inch square, will lift a weight of fifteen pounds attached below. Broader barrel-corks so used will lift more than fifty pounds. The explanation is, that the upper cork raised by the hand prevents the atmospheric pressure on the upper surface of the lower cork, while that pressure of fifteen pounds per square inch continues on the under surface, lifting that cork and the appended weight.—The same result is produced if instead of using the slight caoutchouc tube to exclude the air, a length of glass tube be taken, into

which the two corks, oiled to lessen friction, are introduced like two pistons in the barrel of a syringe.

543. For a like reason, to draw the piston of any good syringe away from the end of its barrel while no air is allowed to enter between them, requires force of fifteen pounds to the square inch of the surface of piston. If this experiment be made in the exhausted receiver of an air-pump, within which the syringe is suspended, the piston will fall away by its own weight. It is then pushed back again, immediately on readmitting the air. Whenever a vacuum — that is to say, a space emptied of air—is produced at the surface of the earth, there is an external pressure of the air around, of the force stated, seeking admittance to the unoccupied space.

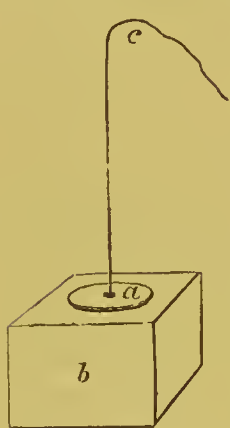
544. An air-pump receiver of about five inches diameter has at least twenty square inches of surface in its upper part or roof, and bears, consequently, a weight or pressure of atmosphere of twenty times fifteen, or three hundred pounds. While it has air within it, this pressure is exactly counterbalanced, and is not sensible; but when exhausted on the plate of the air-pump, it is pressed against the plate with this force. As the atmospheric pressure is in all directions, the pump-plate of course is equally pressed upwards against the receiver, so that the heavy pump itself might be lifted by lifting the receiver. The sides and top of the receiver are also pressed towards each other, which is the reason why air-pump receivers must be made arched or of dome-shape to withstand the great pressure. A flat piece of glass of considerable thickness, laid upon the upper mouth of a receiver, so as to form an air-tight cover to it, is broken instantly by exhausting the air beneath; and a bottle or receiver with flat sides, if exhausted, yields in the same manner.

545. Illustrative of this pressure on solids, there is the experiment of the Magdeburg hemispheres, as it is called. Two hollow half globes of metal, *a* and *b*, are fitted to each other, so that their lips when touching may be air-tight. While there is air between them or within, resisting the pressure of the outward air, they can be separated from each other by overcoming merely their weight; but when the air is exhausted from within by the air-pump, a force is required to separate them of as many times fifteen pounds as there are square inches in the area of the mouth. The

air is extracted by unscrewing one of the handles at *b*, and

then connecting the remaining stalk (which is hollow, and has a stop-cock) with the air-pump.—This experiment merits recollection, because it was one of the first which drew popular attention to the substantial nature and properties of the air; and it astonished the world. Otto Guericke, Burgomaster of Magdeburg, the inventor, had hemispheres made of three feet in diameter, and when he exhausted them, on the occasion of a public exhibition, twenty coach-horses of the Emperor were unable to pull them asunder. There being no air-pump when Guericke began his experiments, although he himself invented one afterwards, he dislodged the air from within the balls by first filling them with water, and then extracting the water by a common pump or syringe applied at the bottom.—It is evident that vessels nearly flat would answer here as well as hemispheres.

546. It is a phenomenon of the same kind, when a boy with his foot presses a circular piece of wet leather, as *a*, against a flat-faced stone, as *b*, and then lifts the stone by pulling at a cord *c*, attached to the centre of the leather. If the leather be so close in its texture that air cannot pass through it, and stiff enough not to be puckered and drawn together too much, a heavy stone may be lifted by it. The contrivance has been called a *sucker*, or *pneumatic tractor*. A very broad tractor, with solid radiating ribs to strengthen it, or with its central part solid, if applied upon a wall would resist the pull of horses like the Magdeburg hemispheres. In the important business of repairing or rectifying street pavements, not a little time and labour might be saved by adding a suitable tractor to the other tools of pickaxes and crowbars now employed, which last can often with difficulty be forced in between and under the stones.



There are some important new uses in surgery which the tractor may serve, as will be shown in the medical appendix to this work.

547. It is from having feet that act on the principle of the tractor, that the common fly and other insects can move along ceilings, and even polished surfaces of glass or metal, with their bodies hanging downwards; and there are many marine animals which attach themselves to rocks, or other objects, by a similar

action. This is now most interestingly seen in the aquarium of the Zoological Gardens in London.

548. It is a fact which has not been noticed in books, that the accident called "sticking in the mud" is often in principle a true case of the sucker as above explained. The leg of a horse or bullock, sunk deep in thick mud, has expelled all air from under and around it, and the attempt to withdraw it is resisted by atmospheric pressure. A second foot plunged in, to enable the sufferer to withdraw the first, is soon in the same predicament. It is erroneously imagined that it is simply the cohesion of the mud or clay which offers resistance. Many of the skeletons of long-legged animals preserved in very ancient bogs or morasses—as of the extinct gigantic deer in Ireland, the great Dinornis in New Zealand, &c.—are found in the standing position, leading to the conclusion that they had perished by "sticking in the mud." The farmers in England call it being *bogged* when young cattle venture into bogs, or other soft watery earth, and would perish there if left to their own efforts. They are extricated often by means of ropes.

549. The nature of the pneumatic tractor is well illustrated by an experiment easily made in a vessel containing a liquid. If a body with a flat surface be applied to the flat bottom of the vessel, so as perfectly to exclude the liquid from between them, the body bears the whole weight of liquid directly over it, and cannot be detached but by corresponding force. The case is striking when a flat piece of cork or leather is pushed against the smooth bottom or side of a vessel containing mercury, and is found not to rise again when the hand is withdrawn from it, but to be firmly held down by the weight of the mercury. We have to remark that in such experiments made in vessels open to the air, the weight of the atmosphere on the liquid adds a pressure of fifteen pounds on every inch of the surface of a body immersed in it.

"*Atmospheric pressure on liquids.*"

550. The pressure of the atmosphere on liquids produces effects more numerous and important than those on solids, above considered. As two familiar examples we may refer to the working of pumps and syphons. All such phenomena, in former times, were referred to an imaginary cause which was called *nature's horror of a vacuum*, or to an obscurely conceived *principle of suction*. It was not until the time of Galileo that their true nature

began to be detected. The discovery has led to many very important results in the arts.

551. The chief cause why the true nature of the phenomena depending on atmospheric pressure was so long unknown, was that the very existence of any gaseous material, forming a deep ocean over the surface of the earth, was not even suspected, and the reason why not, was the fact, that atmospheric air in a state of purity and rest, is absolutely unperceived by any one of the five human senses called the gates or inlets of knowledge. The pure tranquil air of a clear sky is, to simple sense, absolutely invisible, impalpable, without taste, without smell, and giving out no sound. Only lately have men taken and confined portions of it as the stuffing of air-cushions, and have they recognized its material presence in such other facts as enumerated here in Art. 512.

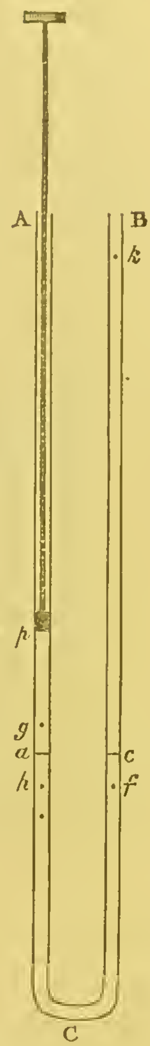
552. Even now persons have difficulty at first in conceiving that a fluid so rare and subtle as air, should be able to resist and to act powerfully upon a dense liquid like water, and they therefore contemplate with much interest such arrangements as that called the Hero's Fountain, described here in Art. 534 (which see). There a column of water of any height, *a b*, is bearing on and entirely supported by a bulk of confined air in the vessel *c*, and that air, compressed by the weight of the water, conveys by its elasticity the whole pressure to the surface of the water in the vessel *d*, and forces up from that a jet of water, *e*, to a height nearly equal to the length of tube from *a* to *b*.

553. That there are fifteen pounds weight of invisible air above every square inch of the earth's surface, is confirmed by the effects above described of the atmospheric pressure on solids: and we now proceed to show that many of the phenomena produced by air among liquids, which phenomena long appeared so mysterious, are but the necessary consequences of the same pressure acting upon them. It will facilitate, to commencing students, the comprehension of these effects, if we first review exactly corresponding effects produced by the obvious agents of one liquid pressing upon another.

554. If into the bent glass tube of uniform size, A B C, mercury be poured in to fill it to a height of about twenty inches, as to *a* and *c*, it will stand at exactly the same level in both branches. (Art. 466.)

If water be then poured into the leg B, it will depress the mercury surface there a certain distance, as *f*, and raise it just

as much above *a* in the tube A; and the length and weight of the mercury in A, greater than in B, will indicate exactly the weight of water poured in; for the fluid masses in the two legs will always exactly balance.



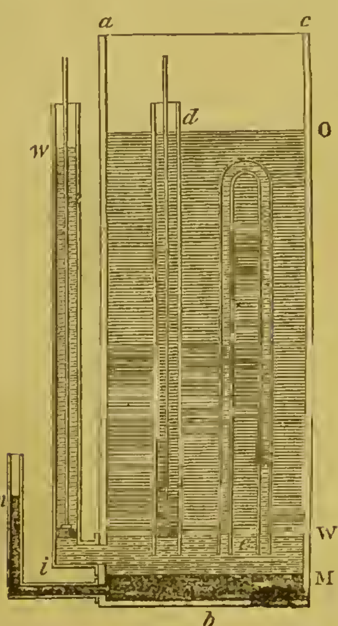
It will be found that an inch of the mercurial column balances very nearly thirteen and a half inches of the water, proving, as is ascertained also by other means described in Art. 482, that mercury is (in round numbers) thirteen and a half times heavier than water, bulk for bulk. By the same means the specific gravity of any other fluid may be ascertained.

If equal weights or pressures of any kind be made on the level surfaces of mercury in the two branches, the level of these will not be disturbed; but any difference of pressure made will be immediately manifested and measured by the changed heights of the columns.

Now the atmosphere presses on the two surfaces described. An air-tight piston *p*, with a valve in it that allows air to pass upwards, but not downwards, may be introduced into the tube A, and pushed down to the surface of the mercury at *a*, expelling all the air which rested on the mercury there. If that piston be then drawn up to near the top of the tube A, there will be no air left in the tube, or a vacuum will be produced there, while the atmosphere continues to press on the mercury within the other tube B; and the difference of height or level between the depressed mercurial surface in B and the raised surface in A, which will be thirty inches in ordinary states of weather, measures accurately the atmospheric pressure. If the tube have an area of one inch square, the weight of mercury so raised is nearly fifteen pounds, and is the exact weight of a column of equal size of air reaching from the earth to the top of the atmosphere. (Art. 538.)

A similar experiment made in long tubes with water instead of mercury shows water pressed up thirty-four feet (in round numbers) into the vacuum, as had to follow from the ascertained difference of specific gravity between mercury and water.

555. It has already been shown, in treating of atmospheric pressure on solids, that the amount of pressure on all things on earth is the same as would be made by a general ocean of oil about thirty-seven feet deep, or an additional ocean of water of thirty-four feet deep. A vessel, then, *a b c*, with water in it up to the level W, and with thirty-seven feet of oil above this, up to the level O, is fitted to illustrate many of the phenomena of atmospheric pressure on liquids. The following are the seven principal cases:—



1st. The weight of the oil pressing with a force of fifteen pounds per inch on the water at W, would not at all disturb the level surface of the water.—Neither does the weight of the atmosphere of fifteen pounds per inch disturb any liquid surface.

2nd. If the oil were gradually poured into the vessel *a b c*, over the water, the water would rise in the tube *i w*, as already explained by the figure (Art. 475); so that when there were thirty-seven feet in height, or fifteen pounds in weight of oil on the inch, the water in *i w* would stand thirty-four feet above its level in the large vessel. If these thirty-four feet of water were then lifted out of the tube by a moveable plug or piston drawn up from the bottom of it at *i*, a second equal quantity would follow the piston, that is to say, would be pressed up by the oil, to be removed, if desired, in the same way as the first, and the tube and piston would constitute a pump.—Now when the atmosphere instead of the oil is allowed to press upon the water-surface in such a vessel, but is excluded from the tube by the action of a piston, the water rises in the tube thirty-four feet, as in the last case; and if this quantity be lifted out of the tube by a piston, or otherwise, a second equal quantity is pressed up, and the tube and piston become a complete example of the common *lifting or sucking-pump*, to be described more particularly hereafter.

3rd. If instead of water there were a quantity of mercury or quicksilver at the bottom of the vessel *a b c*, filling it up to the level M, and if a tube *i m* issued from under this level, the

mercury pressed upon by thirty-seven feet of oil, would rise in this short tube as the water did in the larger; but by reason of its greater specific gravity it would only reach a height of thirty inches above its level, the water, having stood at thirty-four feet.—Now thirty inches of mercury is the height of column which the atmospheric pressure acting in the same way really produces, as is seen in the important instrument made expressly for measuring that pressure and its variations, called a *barometer*, or *measure of weight*.

4th. If a tube *d*, of an inch square, and open at both ends, were plunged into the oil, it would of course always be full up to the level of the oil on the outside of it; and if it were pushed low enough to touch the water at W, it would just contain fifteen pounds of oil resting on an inch square of the water-surface at its mouth; which surface would therefore be bearing a weight of fifteen pounds like every inch of the water-surface around, but would withstand that, owing to the force with which it tended upwards to escape from the pressure corresponding to its depth in the oil. Then if the tube were pushed a little farther down, and if, by a piston or plug in it, the fifteen pounds of oil were lifted out of it, water would rise within the tube until enough had entered to reproduce the pressure of fifteen pounds on the surface below as before; that is to say, the water would rise thirty-four feet, as in the external tube *w i*. This internal tube and piston would again form a *pump*.—In like manner, when a tube open at both ends is plunged from the air into water, the air presses on the surface of the water within the tube, as on the surface around it, with a force of fifteen pounds to the inch, and the two surfaces are not affected by the equal pressures; but if, by a piston, we lift the air out of the tube, as we suppose the oil to be lifted in the last experiment, the water will then rise, following the piston, to the altitude of thirty-four feet. This arrangement of parts is the most usual for the *lifting* or *sucking-pump*.

5th. If a common bottle or vessel of any other shape, as the bent tube *e*, were filled with water, and placed under the oil with its mouth or mouths reaching below the water-surface at the level W, it would remain full of water, owing to the pressure of the oil surrounding it.—For a similar reason, any such vessel or tube, surrounded only by the air, when filled with water, and placed with its mouth or mouths under the surface of the water, remains full; and if such a bent tube has one of

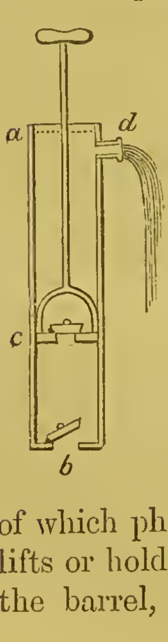
its ends in another vessel lower than the first, a current is established in it towards the lower vessel ;—the arrangement being then called a *syphon*.

6th. A fish in the water below the level W, would be bearing the pressure of the oil from O to W, as well as the pressure of the water.—So a fish in water open to the air, is bearing the atmospheric pressure of *fifteen pounds per inch*, in addition to that of the water itself. This is proved by extracting the air from over water in which a fish is swimming: for then the air-bag of the fish, situated near its under side, as already described, immediately dilates and turns the fish upon its back.

7th. To separate the Magdeburg hemispheres, or to produce a vacuum in any way, under the water level W, would require force proportionate to the weight of oil above, in addition to that required on account of the water :—and to separate the Magdeburg hemispheres under any water-surface pressed upon by the atmosphere, a force is required of *fifteen pounds per inch* beyond what would balance the effect of the water itself.

The following remarks illustrate more minutely some of the objects we have just been explaining.

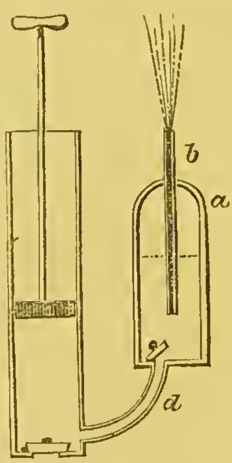
556. The common *lifting-pump* (or *sucking-pump* as it used to be called), is then merely a barrel, *a b*, with a close-fitting moveable plug or piston in it, *c*. When the lower end *b*, is plunged into water, and the piston is drawn up from the bottom, the atmosphere being prevented from pressing on the surface of the water within the tube, the pressure on the surface external to the tube, drives the water up after the piston. That the water which thus rises may not fall again, there is a valve or flap at the lower part of the pump-barrel *b*, which opens only to water passing upwards ; and that the piston may be allowed to pass downwards through the water in the barrel, to repeat its stroke, there is in it a similar valve. The piston, in rising during a second or succeeding stroke, causes all the water above it to run over at the spout *d*.—Formerly a lifting-pump was said to act by *sucking* the water up from the well beneath it; the true meaning of which phrase we now perceive to be, that the piston merely lifts or holds off the air which was pressing on the water within the barrel, and allows the water to rise there in obedience to



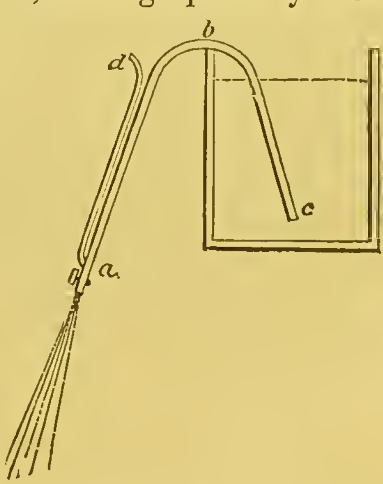
the pressure of the external air around. The reason is apparent then, why, in the pump of suction, the water will only follow the piston to a certain elevation, *viz.*, until its weight balances the external pressure of the atmosphere.

557. The word suction denoted originally an action of the mouth by which fluid is caused to enter it. It means, a momentary slight effort made to enlarge the cavity of the mouth, during which any air confined within it is rendered less dense, and of weaker elasticity than that of the external atmosphere, and therefore any fluid placed between the two forces is moved towards the weaker. The mouth can make only a partial vacuum, and therefore cannot raise liquid very far. The action of the common fire-bellows is of the same kind as is the action of the chest in breathing.

558. When the piston of a pump is solid, or without a valve, as at *c*, the machine is called a *forcing-pump.* The water rises beneath the piston, as already explained for the lifting-pump, but then, as it cannot pass through the descending piston, as in the lifting-pump, it is forced into any other desired direction, as to *d*. A forcing-pump can bring water from only thirty-four feet below the piston, but can send it to any elevation. In forcing-pumps, it is usual to make the water enter an air-vessel *d a* (already explained in Art. 527), from which it is again urged by the elastic air, through the pipe *b*, in a nearly uniform stream.



559. A *syphon* remains full of liquid, although partially raised above the surface of the surrounding liquid, as explained above. (Art. 555.) For common purposes, a syphon is made of the form here represented, *viz.*, a bent tube *c b a*, with one end longer than the other. To use it, the end *c* is first immersed in liquid, and the end *a* being then stopped for the time by the finger or a cock, the air is extracted by the mouth or otherwise, through the small tube *a d*, and the atmosphere immediately fills the whole tube with liquid from *c*. If the instrument be then left to act,



the liquid will run from the longer leg, because a long column of liquid overbalances a short one, until the shorter has drunk up all within its reach. Whether the external extremity be in the air only, or immersed in liquid, makes no difference, except that the immersion shortens by so much the descending column. If both extremities be immersed in liquid, and in different vessels, by alternately lifting one vessel or the other, the liquid will be made to pass and repass, and will come to rest in the syphon only when the surfaces in the two vessels are at the same level. Thus the same leg becomes alternately the long and the short leg, according to the height of the liquid in which it is immersed.

560. A syphon is sometimes made with both legs equal and turned up, as here represented, so that it remains full of liquid although lifted away from the vessel, and therefore is always ready for action. As it is the same cause, atmospheric pressure, which lifts the water in a pump and in a syphon, the top of a syphon must evidently be within thirty-four feet of the water-surface below. In the syphon, as in the cases of balancing liquids, described in Art. 475 (which see), the comparative diameters of the legs is a matter of no importance, nor their oblique length, provided the perpendicular heights of the two columns have the necessary relation:— even an inverted teapot may be used as a syphon, discharging at the spout. This truth is well exemplified in what may be called the *syphon-paradox,* an exact counterpart of the paradox of the "hydrostatic bellows," already explained. If the apparatus of the bellows be filled with water in the ordinary way (see page 164), and be then inverted or turned so that the tube becomes like the long leg of a syphon, the little stream of water issuing from it at *a* will lift as great a weight suspended *from* the board *d*, as the same slender column in the standing position can lift *upon* the board. As farther illustrative of the atmospherical pressure exerted in producing this effect, and in rendering a syphon active, we may advert to the striking fact, that a very long small tube of water screwed into the bottom of a close cask of water so as to communicate with it, and then allowed to discharge like the long leg of a syphon, will cause the cask to be crushed inwards, just as the same tube screwed into the top of the cask, as represented in Art. 432, causes the cask to be burst outwards.

561. The syphon is very useful for drawing off liquids, where there is a sediment that should not be disturbed, or where it is desirable not to make an opening in the lower part of the vessel.

A large syphon, or several smaller ones, would empty a lake or mill-pond over its bank without injuring the bank; or, it would lift a continuous stream of water like that of a great sewer in a town during repairs, over any obstacle of less height than thirty feet, therefore over a street or canal, and with no greater loss of speed than what takes place where a stream is made to dive on one side of an obstacle in an underground channel which rises to the same level on the other side. To fill a large syphon with water that it may act, a convenient way is, instead of pumping out the air from it, to close the two ends for the time, and to pour in water through a cock at the top.

562. Even the Magdeburg hemispheres held together against the pull of twelve horses trying in vain to separate them (Art. 545), do not exhibit more strikingly the existence and force of atmospheric pressure, than a syphon performing such works as above referred to.

563. There is a pretty syphon-toy, called a Tantalus-cup, having in it a standing human figure which conceals a syphon. The short branch of the syphon rises in one leg of the figure to reach the level of the chin, and the long branch descends in the other leg to pierce the bottom of the cup towards a reservoir below. On pouring water into the cup, the syphon begins to act as soon as the water reaches the chin of the figure, and the cup is then quickly emptied.

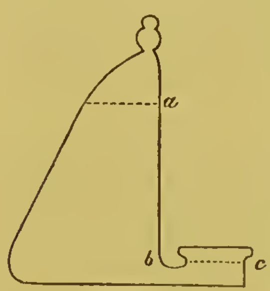
564. Among the infinitely varied water-drains or courses in the bowels of the earth, some are syphons, and produce what are called intermitting wells or fountains. These alternately run and cease for longer or shorter periods, according to the comparative magnitudes of the collecting reservoir and the drain. The reservoir may be an internal cave of a mountain, receiving a regular supply of water by a slow filtering of moisture from above, and the drain any syphon-formed channel, which, like that of the Tantalus-cup, begins to act only when the water in the reservoir has risen to the level of the top of the syphon, and then carries off the water faster than it is supplied. There are some fountains that flow constantly, but at regular intervals have a remarkable increase. In them a common spring is joined with a syphon-spring.

The following facts have close relation to those now explained, as further illustrative of atmospheric pressure on liquids.

565. A long glass full of jelly, if inverted and placed with its mouth just under the surface of warm water, will soon be found to have lost the jelly, and to be full of water in its stead. The jelly is heavier than water, and when melted by the heat sinks down, and is replaced by water from below, forced up by the atmospheric pressure.

566. Some negro servants in the West Indies were detected stealing rum, by inserting the long neck of a bottle full of water through the top aperture of the rum-cask. In such case the water falls out of the bottle into the cask, while the lighter rum ascends in its stead.

567. The common water glass for birdcages has its only opening near the bottom through the neck *b*, into the cup *c*.



Although full of water up to the level *a*, none descends, but when the surface in the open cup *c* falls so low that some air can pass into the glass by the channel *b*, then a bubble of air does pass in and an equal bulk of water comes out, which, by again raising the water-level in the cup, prevents for the time the entrance of more air and the issue of more water. An ink-glass made on this principle preserves the ink well, because there is so small a surface of the ink exposed to the air, while there is always the same depth of ink for the pen to be dipped into.

568. In the common *Argand* or *fountain lamp*, a provision of oil to last for many hours is placed in a vessel like an inverted bottle, higher than the flame, with its mouth immersed in a small open reservoir of oil, nearly on a level with the flame. No oil can descend from above but as the flame consumes the free oil from the small reservoir, and by lowering its level allows a little air to rise and a corresponding bulk of oil to fall.

569. If in a bottle or cask full of liquid and closely corked, a small hole be drilled through the bottom or side, the liquid will not rush out by that, because of the resisting pressure of the atmosphere, and of there not being room in the opening for a current of air to enter while the current of water escapes: but if a second opening be made in the top, a jet from the lower one will follow immediately, for then the atmosphere will press on the upper surface of the liquid as well as on the lower, and the weight of the liquid will be free to act. Thus beer or wine cannot be drawn from a cask by a cock placed near the

bottom, unless what is called a *vent-hole* be made at the top. If the lower opening, however, in any case be so large, as to allow air to enter freely by one side of it, while the liquid is escaping by the other, the vessel may be quickly emptied as in pouring liquid from the mouth of an inverted can or jug. Through an opening of intermediate size there is contention between the entering air and issuing liquid, as seen in decanting a bottle of wine or beer, and there is heard that gurgling sound so pleasing to the ear of the person longing to taste.

570. Even a large mouth, however, at the bottom of a vessel which is close above, may be prevented, by the pressure of the air, from discharging the contained liquid, if the passing in opposite ways of the two currents of air and liquid be rendered difficult. An inverted bottle full of water will not discharge, if a piece of paper be simply applied against its mouth. Even a wine glass or tumbler filled with water may be held with the mouth down, and yet will spill none, if the piece of paper, not very thin, be laid loosely upon its mouth, and be properly supported during the turning. The pressure of the atmosphere against the paper keeps it steadily in its place, and supports the weight of the water above it. Any vessel or tube of water, of less height than thirty-four feet, may be kept closed at the bottom in this way.

The animal body is made up of solids and fluids, and is affected by the atmospheric pressure accordingly.

571. There is difficulty at first in believing that a man's body can be bearing a pressure of fifteen pounds on every square inch of its surface, while he remains altogether insensible of it; but such is the fact, and the reason of his not feeling it is, that the agent pressing is not a solid, urging only downwards, as one stone presses upon another, but is a fluid, producing therefore the fluid compression perfectly uniform all round (Art. 428). If a pressure of the same kind be even many times greater, such, for instance, as fishes bear in deep water, or as a man supports in the diving-bell, it equally remains unnoticed. Fishes are at their ease in a depth of water of which the pressure around would instantly crush inwards almost the strongest empty vessel that could be sent down; and men walk on earth without discovering a heavy atmosphere about them, which, however, instantly crushes together the sides of a square glass bottle when emptied by the air-pump, or even the substance of a thick iron

vessel, left for a moment by any accident without the counteracting internal support of steam or air.

572. The fluid pressure on animal bodies, thus unperceived under ordinary circumstances, may be rendered instantly sensible by an artificial arrangement. In water, an open tube partially immersed becomes full to the level of the water around it, and the water contained in it is supported, as already explained (Art. 429), by that which is immediately below its mouth: now a flat fish with its back bearing closely against the mouth of the tube, would evidently have, acting on its back, the whole of this weight, even if a hundred pounds or more; but the fish would not thereby be pushed away, nor would it even feel its burden, because the upward pressure of the water immediately under it would just counterbalance the weight, while the lateral pressure around its sides would prevent any crushing effect of the merely upward and downward forces. But if, while the fish continued in the situation supposed, the hundred pounds of water were suddenly lifted from off its back by a piston in the tube, the opposite upward pressure of one hundred pounds would instantly crush its body into the tube. At a less depth, or with a smaller tube, the effect might not be fatal, but there would be a bulging or swelling of the substance of the fish into the mouth of the tube.—In air and on the human body a perfectly analogous result may be exhibited. A man without pain or any peculiar sensation, applies his hand closely to the mouth or opening of any vessel containing air, but the instant that the air is withdrawn from within the tube or vessel, the then unresisted pressure of the external air fixes the hand upon the opening, causes the flesh to swell or bulge into it, and makes the blood ooze from any crack or puncture in the skin. These last lines indeed describe closely the surgical operation of *cupping;* the essential circumstances of which are, the application of a cup or glass, with a smooth blunt lip, to the skin of any part of the body, and the extraction by a syringe or other means, of a portion of the air from within the cup.

573. To some minds the exact comprehension of such phenomenon may be facilitated, by considering what would happen to a small bladder or bag of India-rubber full of any fluid and pressed between the hands on every part of its surface except one. At that one part the bag would swell out, and would even burst if the pressure were strong, while no other part would suffer. So in cupping, the whole body except the surface under

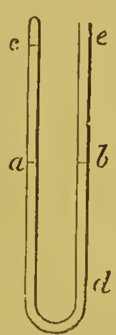
the cup, is squeezed by the atmosphere, with a force of fifteen pounds to the square inch, while in that one situation the pressure is diminished according to the degree of exhaustion in the cup, and the blood consequently accumulates there, causing great swelling. The application of cups with exhaustion only, constitutes the operation called *dry-cupping*. To obtain blood, the cup is removed and the tumid part is cut into by the slight stroke of a number of lancets united: and the cup being then applied again as before and exhausted, the blood issues forth under the diminished pressure. The partial vacuum in the cup may be produced either by the action of a syringe, or by burning a little spirit in the cup and applying it while the momentary dilatation effected by the heat has driven out from it the greater part of the air. The human mouth applied upon any part with the action of sucking, becomes a kind of cupping apparatus, and in cases of poisoned wounds, has been used at the instant as such. The mouth of a leech is such an apparatus with one lancet.

There is a mode of modifying more extensively the atmospheric pressure on the human body, as a remedy, which will be described in the medical appendix.

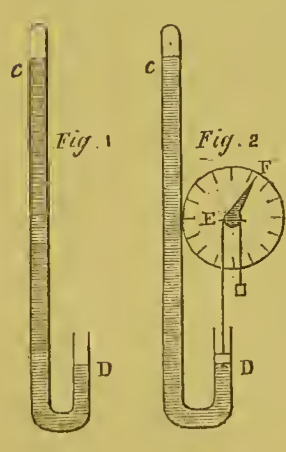
574. The atmospheric pressure on living bodies produces an effect which is rarely thought of, although of much importance, *viz.*, keeping all the parts about the joints closely together by an action similar to that exerted on the Magdeburg hemispheres, or on the united corks described at Art. 542. The broad surfaces of bone forming the knee joint, for instance, even if not held together by ligaments, could not, while the capsule surrounding the joint remained air-tight, be separated by a force of less than about a hundred pounds; but on air being admitted to the articular cavity, the bones at once fall to a certain distance apart. In the loose joint of the shoulder, this support is of great consequence. When the shoulder or other joint is dislocated, there is no empty space left there, as might be supposed, but the soft parts around are pressed in, to fill up the natural place of the bone. When a thigh bone is dislocated, the deep socket called the acetabulum instantly becomes like a cupping-glass, and is filled partly with fluid and partly with the soft solids. In all joints it is the atmospheric pressure which keeps the bones in such steady contact, that they work smoothly and without noise. These important facts had escaped observation until pointed out in the first edition of this work.

575. *The barometer,* we have seen (Art. 554), is a column of fluid supported in an otherwise vacuous tube by the pressure of the atmosphere, and therefore indicating most exactly the degree of that pressure. It is an instrument now of such importance, both in a scientific point of view and in the business of common life, that for the sake of minds which conceive such subjects with difficulty we shall add here the two following illustrations of its nature.

576. If mercury be poured into a bent tube *a b* open at both ends, it will stand at the same level in the two legs, as at *a* and *b*, and the atmospheric air will be pressing on the two surfaces at *a* and *b* with equal force of fifteen pounds per square inch. If the air be then removed from one leg *a*, by a piston or otherwise, while it continues to press in the other leg *b*, the mercury will be pushed down in *b*, until the growing height of the mercurial column in *a* produces a weight so much greater than that in *b*, as just to counteract the pressure: now this balance takes place, in fact, when the mercury in *a* stands about thirty inches higher than in *b*: that being the height of a column of mercury weighing 15 lbs. on the square inch. If the tube *a* were then closed permanently at the top *c*, the mercury would for ever remain elevated in it, marking most perfectly the atmospheric pressure and any variations which it might undergo.

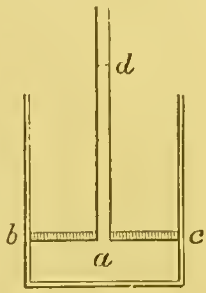


577. Now this construction, only that the empty and useless part of the tube above D is cut off or wanting, forms a common barometer C D. The exact altitude of the mercury in the barometer is known by observing how much the surface near C is higher than that near D. Often, in such a barometer, a little mass of metal is placed to float on the mercurial surface at D, and as it rises and falls, it is caused by a thread passing from it over a wheel or pulley E, Fig. 2, to move an index F like the hand of a clock connected with the wheel, and this index tells the degree of elevation. This modification is called the *wheel barometer*.



578. Again, as water at *a*, in the bottom of a closed pump-barrel, if pressed upon by the piston *c*, of which the rod *d* were

hollow or tubular, would rise in the rod to a height proportioned to the pressure made by the piston: so, in a straight exhausted barometer-tube closed at the top to prevent atmospheric pressure within it, the mercury rises, because the atmospheric pressure on the mercury in a cup into which the tube dips is as the piston forcing the fluid up. To make a barometer of this kind it is necessary only to procure a glass tube about thirty-four inches long, close at one end, and then having filled it with mercury, to plunge its mouth (stopped by the finger while turning) into a small cup or basin of mercury:—the fluid then falls away a little from the top of the tube, leaving a vacuum there, and stands at the elevation which the atmospheric pressure is fitted to maintain. We know, from the law of hydrostatics already explained (Art. 475), that it is of no importance, in such a case, what the size of the tube may be, as it is the perpendicular height which measures the pressure.



In the construction of barometers the liquid most suitable is mercury, because of its great weight in small bulk, a column of mercury of about thirty-one inches serving where a column of water would be required of thirty-five feet. Water barometers, however, are used in various places.

579. The steps of progress towards the invention of the barometer were nearly as follows: Galileo had found that water would not rise under the piston of a pump to a height greater than of about thirty-four feet, and he concluded that it was a pressure of the atmospheric air which caused the rise. His pupil Torricelli, conceived the happy thought, that the atmosphere was pressing by its weight, and concluded that mercury, which is about thirteen and a half times heavier than water, should rise under the same influence to only a thirteenth and half of the water elevation:—he tried and found that this was so, and the mercurial barometer was invented. Pascal then, seeking further evidence that the weight of the atmosphere was the cause of the phenomenon, carried the tube of mercury to the tops of buildings and up the sides of mountains, and found that the mercury fell always in exact proportion to the amount of atmosphere left below it;—and he found that water-pumps in different situations varied as to sucking power, according to the same law.

580. It was afterwards discovered, by continued observations

of the mercurial barometer, that even when remaining in the same place, it did not always stand at the same elevation; in other words, that the weight of atmosphere over any particular part of the earth was frequently fluctuating considerably; a truth which, without the barometer, could never have been suspected. These observations of the instrument being carried still farther, gradually showed, that in serene dry weather the mercury generally stood comparatively high, and that before and during storms and rain it fell:—the instrument therefore might serve as a prophet of the weather, becoming a precious monitor to the husbandman or the sailor.

581. The reasons why the barometer rises and falls in connection with states of the weather, will be farther considered in a coming section, but we may remark here that if rain form in the clouds and then fall to the earth, the atmosphere there loses part of its weight, and if winds blowing from opposite quarters meet, there must arise at the place an accumulation or heaping up of air, with increase of weight. Knowledge of such facts constituting the science of *Meteorology*, has now advanced so far that the government in England has instituted a scientific Board, under the able direction of Admiral Fitzroy, to receive constantly in London, through the electric telegraph, information from all quarters, and by the same means to spread the gathered knowledge, with warnings founded on it, to other stations.

582. To the husbandman the barometer is of considerable use, by aiding and correcting the prognostics of the weather which he draws from local signs familiar to him; but its great use as a weather glass regards the mariner, who has to roam over the whole ocean, and is often under skies and climates altogether new to him. The watchful captain of the present day, trusting to this extraordinary monitor, is frequently enabled to take in sail, and to make ready for the storm, where in former times the destructive visitation would have fallen upon him unprepared.—The marine barometer has not yet been in general use for many years, and the writer of this work was one of a numerous crew who probably owed their preservation to its almost miraculous warning. It was in a southern latitude; the sun had just set with placid appearance, closing a beautiful afternoon, and the usual mirth of the evening watch was proceeding, when the captain's order came to prepare with all haste for a storm. The barometer had begun to fall with appalling rapidity. As yet, the oldest sailors had not perceived even a threatening

in the sky, and were surprised at the extent and hurry of the preparations: but the required measures were not completed, when a more awful hurricane burst upon them than the most experienced had ever braved. Nothing could withstand it; the sails, already furled and closely bound to the yards, were riven away in tatters: even yards and masts themselves were seriously disabled. Such, for a few hours, was the mingled roar of the hurricane among the rigging, of the waves around, and of the incessant peals of thunder, that no human voice could be heard, and amidst the general consternation, even the trumpet sounded in vain. In that awful night, but for the little tube of mercury which had given the warning, neither the strength of the noble ship, nor the skill and energies of the commander, could have availed to save, and not a man would have survived to tell the tale. On the following morning the wind was again at rest, but the ship lay upon the yet heaving waves, an unsightly wreck.

583. The marine barometer with mercury differs from that used on shore, in having its tube contracted in one place to a very narrow bore, so as to prevent that sudden rising and falling of the mercury, which every motion of the ship would else occasion.

584. But a barometer less easily damaged than that containing mercury, called the *Aneroid* (*devoid of air*), has now been invented, which serves at sea as perfectly as on land. It is a flat round box of small size, made of thin elastic metal plate. It is nearly emptied of air, and then hermetically closed. The pressure of the atmosphere acting on the elastic top and bottom forces the centres of these nearer together, and more or less in proportion as the pressure varies. A combined lever arrangement, connected with the centres, tells exactly the varying degrees of their approximation or compression, by moving an index like the hand of a watch, pointing to a line of figures which correspond with the divisions engraved on the face of the common barometer.

Civilized Europe is now familiar with the barometer and its uses, and therefore, that Europeans may conceive the first feelings connected with the discovery of it, they almost require to witness the astonishment or incredulity with which people of some other countries still regard it. A Chinese merchant once conversing on the subject with the author, could only imagine of the barometer, that it was a gift of miraculous nature, which the God of Christians had given them in pity, to direct them in the

long and perilous voyages which they undertook to unknown seas.

585. A barometer is of great use to persons employed about those mines in which *hydrogen gas*, or *fire-damp*, is copiously generated and is harboured among the excavations. When the atmosphere becomes unusually light, the hydrogen being relieved from a part of the pressure which ordinarily confines it to its holes and lurking-places, expands or issues forth to where, mixed with common air, it may meet the lamp of the miner, and explode to his destruction. In heavy states of the atmosphere, on the contrary, it is pressed back to its hiding-places, and the miner may advance with comparative safety.

We see from this that any reservoir or vessel containing air would itself answer as a barometer if the only opening to it were through a long tubular neck, containing a elose-sliding plug with little friction; for then, according to the weight and pressure of the external air the density of that in the vessel would vary, and all changes would be marked by the position of the moveable plug. A barometer has really been made on this principle by using a vessel of glass, with a narrow horizontal neck, in which a globule of mereury serves as the moveable plug.

586. The state of the atmosphere, as to weight, differs at different times in the same situation, so much as to produce a range of about three inches in the height of the mercurial column; that is to say, the height of the mercury may vary from about twenty-eight to thirty-one inches. On the occasion of the great Lisbon earthquake, in 1755, the mercury in the barometers fell so far, even in Britain, as to disappear from that portion at the top usually left uncovered for observation.—The uncovered part of a barometer is eommonly of five or six inches in length, with a divided scale attached to it, on which the figures 28, 29, &e., indicate the number of inches from the surface of the mercury at the bottom to the respeetive divisions:—on the lower part of the scale the words *wind* and *rain* are generally written, meaning that when the mereury sinks to them, wind and rain may be expected; and on the upper part, *dry* and *fine* appear, for a eorresponding reason: but it is to be recollected, that it is not the absolute height of the mercury whieh indicates the eoming weather, but the recent changes in its height:—a falling barometer usually telling of wind and rain; a rising one of serene and dry weather.

587. The barometer answers another important purpose, besides that of a *weather-glass*—in enabling us to ascertain readily the height of mountains, or of any situation to which it can be carried.

As the mercurial column in the barometer is always an exact indication of the weight or pressure of air which is above its level, being indeed, as explained in the foregoing paragraphs, of the same weight as a column of that air of equal base with itself, and reaching from it to the top of the atmosphere,—the mercury must fall when the instrument is carried from any lower to any higher situation, and the degree of falling must always tell exactly what proportion of the atmospheric air has been left below. For instance, if thirty inches barometrical height mark the whole atmospheric pressure at the level of the sea, and if the instrument be found, when carried to some other situation, to stand at only twenty inches, it proves that one-third of the substance of the atmosphere exists below the level of the new situation. If the atmospheric ocean were of as uniform density all the way up as an ocean of water is, a certain weight of air thus left behind in ascending would mark everywhere a nearly equal change of level, and the ascertaining any height by the barometer would be a very simple calculation. The air at the surface of the earth being nearly twelve thousand times lighter than its bulk of mercury, an inch rise or fall of the barometer would mark everywhere an ascent or descent in the atmosphere of nearly twelve thousand inches or one thousand feet. But owing to the elasticity of air, which causes it to increase in volume as it escapes from pressure, the atmosphere is rarer in proportion as we ascend, so that to leave a given weight of it behind, the ascent must be greater, the higher the situation where the experiment is made: the rule, therefore, of one inch of mercury for a thousand feet, holds only for rough estimates near the surface of the earth. The more precise calculation, however, for any case, is still easy; and a good barometer, with a thermometer attached, and with tables, or an algebraical formula expressing all the influencing circumstances, enables travellers to ascertain elevations much more easily, and in many cases more correctly, than by trigonometrical survey.

588. The weight of the whole atmospheric ocean surrounding the earth being equal to that of a watery ocean of nearly thirty-four feet deep, or of a covering of mercury of thirty inches, and

the air at the surface of the earth being about 800 times lighter than water, if the same density existed all the way up, the atmosphere would be 34 times 800 feet high, equal to about five miles and a half. On account of the greater rarity, however, in the superior regions, it really extends to a height of nearly fifty miles. From the known laws of aërial elasticity, explained at Art. 520, we can deduce what is found to hold in fact, that one-half of all the air constituting our atmosphere exists within three miles and a half from the earth's surface; that is to say, lies under the level of the summit of Mont Blanc.

589. In carrying a barometer from the level of the Thames to the top of St. Paul's Cathedral, or of Hampstead Hill, the mercury falls nearly half an inch, marking an ascent of about five hundred feet. On Mont Blanc it falls to half of the entire barometric height, marking an elevation of fifteen thousand feet; and in Du Lac's famous balloon ascent it fell to below twelve inches, indicating an elevation of twenty-one thousand feet, the greatest to which man in that day had ascended from the surface of his earthly habitation. Since then still greater heights have been attained, particularly by Mr. Glaisher, F.R.S., in his series of balloon ascents made for scientific purposes in the years 1862 and 1863.

590. The extreme rarity of the air on high mountains must of course affect animals. A person breathing on the summit of Mont Blanc, although expanding his chest as much as usual, really takes in at each inspiration only half as much air as he does below—exhibiting a contrast to a man in the diving-bell, who, at thirty-four feet under water, is breathing air of double density, at sixty-eight feet of triple, and so on. It is known that travellers, and even their practised guides, often fall down suddenly or faint when approaching lofty summits, on account chiefly of the thinness of the air which they are breathing, and some minutes elapse before they recover. In the elevated plains of South America, the inhabitants have larger chests than the inhabitants of lower regions—furnishing another admirable instance of the animal frame adapting itself to the circumstances in which it is placed. It appears from all this, that although our atmosphere is fifty miles high, it is so thin beyond three miles and a half, that mountain ridges of greater elevation are nearly as effectual barriers between nations of men, as islands or rocky ridges in the sea are between the finny tribes inhabiting the opposite coasts. The intense cold which appertains to high

situations, and forms another obstacle to human approach, remains to be considered in our next division.

591. A barometer connected with an air-pump, indicates exactly the progress and degree of exhaustion in the receivers. When the mercury falls to half its height, it shows that half of the air is extracted; and so for all other proportions. A barometer then is a necessary addition to a complete air-pump; but as its chief purpose is to mark when the exhaustion is carried nearly to completion, a very short tube, corresponding to the bottom of a common barometer, is all that is generally provided, and it is usually made of bent form.

592. The ingenious method, devised by Sir John Leslie, of ascertaining the specific gravity of the solid material forming any porous mass or powder, includes the agency of a barometer. It proceeds upon this reasoning. The interstices of a porous or pulverized mass are filled with air of the density of the surrounding atmosphere, and if the atmospheric pressure on which that density depends be diminished upon the mass in any known degree, an exactly corresponding proportion of the air will issue from the pores. This, if measured, will declare the whole quantity, and therefore the amount of interstice or pores in the solid mass. Now if the substance were enclosed in a small vessel of known dimensions attached at the end or bottom of a syringe of known dimensions, the pressure of the atmosphere might be held off from it in any degree by drawing at the piston, and the air would issue from the pores as described, and would follow the piston; but as, owing to the friction of a solid piston, it would be difficult to measure the precise traction made, the liquid piston of a mercurial column has been substituted, of which the force is always proportioned to the length of column. The operator takes an open glass tube, *a e*, of known dimensions, and prepares a part of its top, *a b*, as a receptacle for the substance under trial, by affixing a partition at *b*, which shall support the substance, but allow passage to air. Having then filled *a b* with the substance, he gradually immerses the tube in a vessel of mercury *d f*, until the mercury stand both inside and outside of the tube at the level of *b*, the air from the tube having passed out through the substance in *a b*. It is evident that on then closing the tube at *a* in an air-tight manner, and lifting the tube, a column of mercury will remain

standing in it, above the level of the external mercury at *d*, and will be acting as a piston pulling down from *b* with force proportioned to its height. If the tube be lifted until such mercurial column *c d* be just of half the length of the column in a common barometer, the air in the pores of the substance will be relieved from half of the atmospheric pressure, and will dilate to double bulk; so that while half of the air will remain in the pores, the other half will have issued forth to occupy a space, as *b c*, between the surface of the mercury and the partition at *b*. This space, *b c*, therefore, will be exactly equal to the amount of the pores or interstices; and as it may be measured and compared with the whole space *a b*, its ascertained magnitude will solve the problem. It has been found in this way that charcoal, which is usually said to be only half as heavy as its bulk of water, is really formed of matter nearly four times as heavy; proving, in a new way, the identity of charcoal and diamond: and that light pumice-stone consists of matter as heavy as granite or marble. This very ingenious application of the barometer may lead ultimately to other useful results; and the contrivance merits consideration here, as exhibiting under a new and interesting aspect the rationale of barometric action and the elasticity of air.

The degree of atmospheric pressure determines the liquid or the aëriform state of many substances. (See the Analysis, page 203.)

593. It has already been stated that permanent gases—or substances usually met with in the aëriform state—may be reduced to the liquid, or even solid form, by simple pressure, and abstraction of the heat which exists in them while in the aëriform state. Carbonic acid, and other gases, have been treated in this way. And it became an interesting question whether many of the substances commonly seen as liquids on the face of the earth, where they are bearing the pressure of the atmosphere, would have the form of liquid if that pressure did not exist.

On investigating this subject by experiment, we accordingly find, that *æther*, *alcohol*, or *ardent spirits*, *volatile oils*, *&c.*, and even *water* itself, are known to us here as liquids, only because their particles are kept together by the weight and pressure of a superincumbent atmosphere. Any of these substances, relieved by art from such pressure, quickly becomes an air or gas, just as

carbonic acid gas or any other which has been kept in the state of liquid by any greater pressure, becomes air again on being relieved.

In our first chapter we explained the dependence of the three forms which any body may assume, *viz.*, of solid, liquid, or air, on the quantity of heat diffused among the particles: we now see, however, that to understand the subject completely, we must consider also the effect of accidental pressure; for, while heat is the power separating the atoms in the changes mentioned, it has to overcome both the mutual attraction of the atoms and the additional force of the atmosphere pressing them together. The combined influence of these forces is fully displayed in the two phenomena called *boiling* and *evaporation*, which exhibit the progress of the change of a liquid into an aëriform fluid. We now proceed to examine these phenomena.

594. *Boiling.*—If water be placed in a suitable vessel (it may be a glass flask) over a common fire, or over the flame of a lamp, it is gradually heated to a certain degree; and then small bubbles of aëriform matter, *viz.*, water, in the state called steam, are seen forming at the bottom of the vessel, and successively rising to the surface, where they disappear by mixing with the atmosphere; and the operation being continued, the quantity of water diminishes with every bubble, until the whole vanishes under the new form of air.

595. This change takes place in water, under common circumstances, at the degree of heat marked 212° on Fahrenheit's thermometer, and called on that account the *boiling point* of water; at which degree, therefore, the repulsive power among the particles is just sufficient to overcome both their natural attraction, and the compressing force of the atmosphere of fifteen pounds on the inch. But a less degree of heat suffices if the pressure of the atmosphere be lessened or removed; and a greater degree is required if pressure be increased. Water on the top of Mont Blanc boils at 180°, because relieved from the pressure of the air which is below the level of the mountain's summit; and at all intermediate heights in descending to the level of the sea, or beyond that into mines, there is a corresponding increase of the boiling temperature. So exactly is this the case, that a good method of ascertaining the heights of different places is found to be merely to observe the heat of boiling water at them. To many persons the information here given that boiling water is not equally hot in all places, will appear extra-

ordinary: but they will now understand the reason, and, further, that even in the same place, at different times when the barometer is higher or lower than usual, there will be corresponding differences.—Again, near the bottom of a boiler, the water is hotter than above, because it is bearing an additional pressure, proportioned to the depth, and does not therefore take the form of steam so readily as it would if a little higher up. In very large and deep boilers, therefore, such as are used in great porter breweries, the boiling liquid is much more heated than it can be in smaller vessels;—a circumstance which probably has an influence on its ultimate quality.

596. While water under common atmospheric pressure, or when the barometer stands at thirty inches, boils at 212°, other substances, with other relations to heat, have their *boiling points* higher or lower:—æther, for instance, boils at 98°; spirit or alcohol at 174°; fish-oil and tallow at about 600°; mercury at 650°. This explains why a burn from boiling oil is so dreaded, and why flesh or fish boiled in water is so different from what is cooked by frying or otherwise in melted fat or in oil.

597. It is in consequence of the different temperatures at which the particles of different substances acquire repulsion enough to rise against the atmospheric resistance, that we are enabled to perform the operation called *distilling.* If any fermented fluid, for instance, containing alcoholic spirit and water, as wine, beer, &c., be heated up to 180°, the spirit will pass off in the aëriform state, leaving the water behind, and may be caught apart and cooled to liquid condensation in any fit receiver. Distillation is the only means we possess of separating many substances from each other: as spirit from wine or any other fermented liquor; various acids from water; pure water itself from the salt of sea-water or other impurity;—and even the separation of mercury from silver or gold which it has been employed to dissolve from among the rubbish of a mine or river-bottom, is merely a distillation which saves the mercury to be used again.

598. We must recall to mind here what was mentioned in a former part of the work (Art. 52), that a large amount of heat enters into every substance during the change of form from solid to liquid, or from liquid to air;—which quantity, from not remaining sensible to the thermometer, has received the name of *latent* or *concealed heat.* The whole of this is given out again

in the contrary change. In the conversion of water into steam, the heat which thus disappears is about 1,000 degrees, or six times as much as is required to raise the cold water to the boiling point: this is proved by the time and fuel expended in boiling any quantity to dryness, and by the fact that a pint of water in the form of steam will combine instantly with six pints of cold water, raising the whole to boiling heat.

But for the fact of latent heat, the conversion of a liquid into an aëriform or gaseous mass would not be the gradual process of boiling which we now see, but a sudden and terrible explosion: for when any quantity of water were raised to the boiling heat, one degree of heat additional would be sufficient to convert the whole into steam. And but for the same reason, the thawing of winter snow would always be a sudden and frightful inundation; the whole load of a mountain or plain becoming at once as a lake bursting from any enclosing barriers. On the other hand, if water in freezing had not to give out gradually its latent heat, after any quantity were once cooled down to the freezing point, the abstraction from it of one degree more would instantly convert the whole into a solid mass. Thus, then, by admirable arrangement effecting most important purposes in nature and art, all changes from solid to liquid and from liquid to air, and the reverse changes, are very gradual.

600. If a little heat be abstracted from steam, a small part of the steam proportioned to the abstraction is immediately condensed into water. What is called steam in common language—as the vapour which becomes visible at a little distance from the spout of a boiling kettle or the chimney of a tea-urn—is not truly *steam*, but small globules of water already condensed by the cold air and mixed with it. True steam is as dry and invisible as air itself; but the instant that it comes in contact with air or other bodies colder than itself, the cooled part becomes water. A kindred phenomenon is seen when a person directs his warm breath (which has always some water invisibly mingled with it) against a window pane or looking-glass, or any polished metallic surface, colder than the breath; a cloud or dimness immediately covers the surface because the water of the breath is condensed upon it.

By means of the exhausting air-pump on one hand, and of the condensing syringe on the other, all the above-described phenomena, depending on the atmospheric pressure, and its increase or diminution, may be strikingly shown.

601. Thus, to exhibit the effect of diminished pressure, water not heated by several degrees to the ordinary boiling point of low situations, but which would be boiling at the top of Mont Blanc, is caused to boil instantly by placing it under the receiver of an air-pump, and making a few strokes of the piston. If the exhaustion be rendered nearly complete, the water will rise, even when colder than the blood of animals; and at degrees of temperature still much lower, it will at the surface be assuming the form of air, although not with force sufficient to produce the visible agitation of boiling. Other liquids, as alcohol, æther, &c., from requiring inferior degrees of heat to separate their particles to aëriform distances, boil under the receiver of an air-pump at very low temperatures; æther, for instance, when as cold as freezing water.

602. On the other hand, to exhibit the effect of increased pressure, if we confine the particles of a liquid still more than by a common atmospheric or equivalent pressure, degrees of heat higher than the common boiling point will be required to separate them. In a diving-bell, the boiling point of water is higher than 212° in proportion to the depth which the bell has reached: and if, at the surface of the earth, we heat water in a close vessel into which air is forced so as to press thirty pounds on the inch instead of fifteen, as the atmosphere does; or from which we prevent the steam's escaping until it has acquired the force of a double atmosphere, we shall, before making the liquid boil, have to raise the heat, in a corresponding proportion beyond 212°. Under a very strong pressure, water may be rendered almost red-hot, but the force with which its particles are then tending to separate is almost that of inflamed gun-powder. Even then, however, if a gradual issue were allowed, only a certain quantity of the water would absorb and render latent the existing excess of heat above 212° and would become common steam, leaving behind a considerable portion as boiling water of the ordinary temperature.

The fact that liquids are driven off, or made to boil at lower degrees of heat when the atmospheric pressure is lessened or removed, has recently been applied to some very useful purposes.

603. The process for refining sugar is to dissolve the raw sugar in water, and after clarifying the solution by straining or otherwise, to boil off or evaporate the water again, that the dry

crystallized mass may remain. Formerly this evaporation was performed under the atmospheric pressure, and a heat of at least 220° was required to make the syrup boil; by which high temperature, however, a considerable portion of the sugar was discoloured and rendered uncrystallizable. The valuable thought occurred in the beginning of this century, to Mr. Howard, F.R.S., eminently skilled in chemical science, that the water of the solution might be drawn off or evaporated at a very low temperature by boiling the syrup in a vacuum, that is to say, in close pans, which would exclude the atmospheric pressure. This was accordingly done, and the value to the inventor of the patent right was said to have exceeded thirty thousand pounds a year. The syrup during the process was not heated to beyond 150°.

In the preparation of many medicinal substances the process of boiling *in vacuo* is equally important. Many extracts from vegetables have their virtues impaired, or even destroyed, by a heat of 212°; but when the water used in making the extract is driven off *in vacuo*, the activity of the fresh plant remains in the extract.

In the same manner, in the process of distillation of the essential oils of vegetables, which is merely the receiving and condensing again in appropriate vessels an aëriform matter raised by heat from the vegetable mass, those which are changed and injured by an elevated temperature may be obtained of perfect quality by carrying on the operation in a vacuum. The essential oils of lavender, peppermint, and others are said to have their natural flavour better preserved since this plan has been adopted.

The apparatus for evaporating and distilling *in vacuo* consists of vessels strong enough to bear, when quite empty, the external atmospheric pressure. They are made, therefore, of arched form. The vacuum is produced and maintained by air-pumps worked by steam-engine or other power.

604. If this valuable apparatus could be used generally in the countries where sugar is produced from the juice of the sugar-cane, more sugar than now, and of superior quality, would be obtained from a given quantity of juice. The complete apparatus, however, is costly at first, is of complex construction, and requires delicate management where skilled labour is difficult to obtain, and if damage occur engineers capable of repairing are far away. Complete interruption of the work

from any cause would bring heavy loss to the proprietor who had trusted to the superior apparatus. Under these circumstances, it has appeared to the writer that the simple plan now

to be described would in many places render service. It is merely to establish a communication between a close boiler, as *a*, and the vacuum at the top of a water-barometer, as *b*. To produce that vacuum, the strong vessel *b* forming the top of the barometer, and thirty-six feet of tube below, reaching to *d*, are first filled with water through a cock *c* at the top; this cock being then shut, and another cock *d* at the bottom, which had been shut, being opened, the water sinks down out of the vessel *b*, until the column in the tube is only thirty-four feet high, as at *f*, that being the height which the atmosphere will support. On then opening a communication between the boiler *a* and the vacuum in *b*, the operation will go on as desired, and the steam rising from *a* may be condensed in *b* by a little stream of cold water allowed constantly to run through and be scattered from above. This water, it is evident, will always pass downwards, becoming part of the barometer column below, without filling up or impairing the vacuum. If air should find admittance in any way, the original degree of vacuum can always be easily reproduced as at first; and to prevent interruption from this cause, it might be convenient to have two vessels like *b*, of which one could always be in action while the other was being emptied of air. On many sugar estates there is a fall of water, fit to supply the barometer without the trouble of pumping; but even the expense of pumping by hand or horse-power would not be deemed waste for the end here sought. The tube *d c* needs not to be perpendicular, provided it be longer in proportion to its obliquity; and it may be very small: some yards of common lead-pipe would answer.

605. When it was understood that, at common temperatures, water and many other liquids would be existing in the form of air, but for an atmospheric pressure opposing the separation of the particles, it became of great importance in many of the arts, and for comprehending certain phenomena of nature, to ascertain, very exactly, with respect to some of these liquids, water

particularly, the degrees of expansive force belonging to them at different degrees of temperature. The subject, as water is concerned, has been investigated with great care, and the following table shows part of the results. The left-hand column marks temperatures rising from 32° of Fahrenheit's thermometer, or the freezing point of water, to 290°; and the right-hand column marks the corresponding degrees of force with which the water tends to expand into the state of steam, and therefore also, the force and density in any vessel of the steam confined above the water which it contains. One ounce and a half per square inch is the expansive force exerted on the sides of any containing vessel by the steam rising from freezing water, that is to say, the force with which freezing water seeks to dilate into steam or air; and sixty pounds per inch is the force of water heated to 290°. To many readers the idea will be quite new and surprising, that if some freezing water, or even ice, be inclosed in a bladder or bag of caoutchouc containing nothing else, and the bladder or bag be lodged in the exhausted receiver of an air-pump or other vacuum, the bladder will quickly be distended with steam strong enough to support a weight of one ounce and a half on a square inch of its surface.

606. At 32° force of steam is $1\frac{1}{2}$ oz. per inch.

50	$2\frac{3}{4}$	"
100	13	"
150	4	lbs.
180	$7\frac{1}{2}$	"
212	15	"
250	30	"
272	45	"
290	60	"

In this table we have to remark how much more rapidly the tendency to dilate into steam increases, than the temperature of the water: for a rise of eighteen degrees, *viz.*, from 32° to 50°, at the beginning of the scale, only increases the dilating force *one ounce and a quarter* on the inch, while an equal rise of 18° at the end of the scale, *viz.*, from 272° to 290°, increases it *fifteen pounds*. It is important to distinguish, however, between the *tendency to form steam* at any temperature, and the *quantity of steam* produced by a given quantity of heat; for the matter imperfectly understood has led to many vain schemes for improving the *steam-engine*. The fact is, that *high-pressure steam* is merely *condensed steam*, as *high-pressure air* is *condensed*

air; in other words, the density of steam is greater, or there must be more of it in a given space, exactly as its force is greater, according to the rule explained at page 209; and the heat expended in its formation being proportioned to the quantity of steam in a given space, or the density, the force and the cost in fuel have always nearly the same relation to each other. In one pint of steam at 290°, having an elastic force of sixty pounds on the inch, there is very nearly four times as much water and four times as much latent heat as in one pint of steam at 212°, which has a force of fifteen pounds on the inch,—indeed, the one pint at 290° may be changed into the four pints at 212°, or the contrary, by merely lessening the pressure. It does not accord with the plan of this general work to enter farther into the details of this subject, but they may be found in all treatises on the steam-engine.

607. Seeing the rapid increase of the expansive force in the above table, we have the explanation of the terrible effects occasionally produced by confined water when overheated. A boiler of any kind, completely closed, and having no safety valve, if heated to a certain degree, will explode as if charged with gunpowder. Unhappily the instances are too numerous where the incautious or ignorant use of steam has led to explosions, which have demolished the containing buildings and shattered whole neighbourhoods.

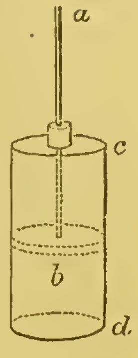
608. The prodigious force generated by heating water would at first only surprise and terrify men, but in the course of time would lead inventive minds to inquire whether it might not be turned to use; in other words, whether some mechanism, to be called a *steam-engine,* might not be contrived to enable men to employ it in their various labours. To this inquiry, after numerous less successful attempts, a glorious answer was given, not yet a century ago, by the illustrious WATT:—and to this part of our work it belongs to consider what through his genius has been accomplished.

The Modern Steam-engine

during the lives of people still living has changed the character of human industry, and may almost be said to have elevated man in the scale of existence.

609. The name of *steam-engine,* to most persons, brings the idea of a machine of the most complex nature, and hence to be understood only by those who will devote much time to the

study of it; but he who can understand a common pump, may understand a steam-engine. It is, in fact, only a pump in which the fluid passing through it is made to impel the piston instead of being impelled by it, that is to say, in which the fluid acts as the *power* instead of being the *resistance*. It may be described simply as a strong barrel or cylinder *c d*, with a closely-fitting piston in it, here shown at *b*, which is driven up and down by strongly expansive steam admitted alternately above and below it from a suitable boiler; while to the end of the piston-rod *a*, at which the whole force may be said to be concentrated, there is attached in some convenient way the work which is to be performed. The power of the engine is of course proportioned to the size or area of the piston, on which the steam acts with a force, according to its density, of from 15 to 100 or more pounds for each square inch. In some of the Cornish mines, and in great steam-ships, there are cylinders and pistons of more than ninety inches in diameter, on which the pressure of the steam equals the effort of six hundred horses.

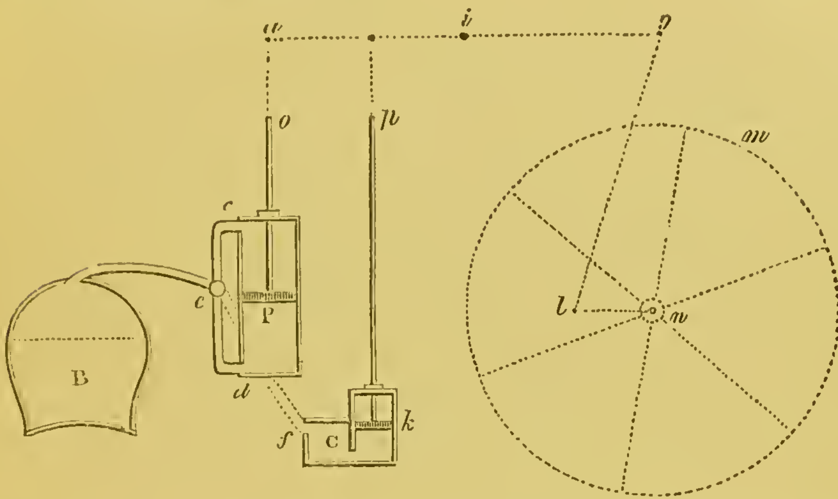


610. It is very interesting to review the steps by which the newly-awakened power of steam has been adapted to the different kinds of labour in which it is now employed. The first, being the most obvious application of a force moving alternately up and down, was to the pumping of water on a great scale. This had to be done in mines, many of which would be valueless if the water constantly draining into them could not be removed at a moderate cost. It has to be done also in supplying and distributing water in towns. Now at the mouth of many a mine may be seen the wonder-working piston-rod connected with one end of a great vibrating beam, to the other end of which a huge water pump is attached, which sends out a torrent from the bowels of the earth. Again, a single engine pumping from a pure stream or deep well at a distance perhaps of miles from a city suffices to maintain an abundant supply for all the reservoirs, baths, fountains, &c., of a numerous population. A next step in advance was the addition to the powerful piston-rod of the crank and ponderous fly-wheel, by which the interrupted up-and-down strokes were converted into a smooth turning or rotatory motion as uniform as that of a wheel driven by a waterfall, and thus it became applicable anywhere to the working at small cost of all kinds of machinery, such as water-power

and other powers had worked before. One steam-engine, now stretching long arms over a great barrack or manufactory, keeps in one quarter, thousands of spinning-wheels in motion, while in another it is carding and preparing the material of the thread, and in another weaving the cloth. One steam-engine in a great metropolitan brewery may be employed by turns, in grinding the malt, pulling up supplies of all kinds from waggons around the building, pumping cold water from deep wells into some of the coppers, sending the boiling wort from others to the cooling floors or apparatus above, lifting the casks about, loading the drays, and so forth—in a word, performing alone or aiding in the labours of a multitude of distinct workers. There soon sprang up corn-mills, saw-mills, block-making machines, coining machinery, printing-presses, and numberless other such things all moved by steam. Some of these now accomplish works of such magnitude as, but for the resistless force of steam to aid them, men would never have attempted; for instance, where huge mechanic hands take hold of heated lumps of iron and quickly afterwards return them rolled into thin sheets, or formed into uniform bars and rods, as if the iron had become to them like soft clay in the hands of the potter. After a time came what many persons regard as the greatest marvel of all—the application of steam to locomotion. At this moment already, over great part of the world, the piston-rod with its crank, is on land driving with the speed of the wind in all directions, railway trains, loaded with passengers and merchandize, and on the water is propelling by paddle-wheels and screws innumerable steam-ships. These ships, setting at defiance the violence of winds and waves at sea, and the currents of the fleetest rivers traversing the lands, are carrying men and civilization over the whole globe. Many regions until lately little known beyond their own confines are now by the steam-engine, called, so to speak, from their solitude to become parts of the one great garden of the earth which civilized man will fully cultivate. Such are the prodigies which Watt's invention has already effected, and new applications are still daily being made.

611. The following account of the parts of the steam-engine is intended, without entering into minute practical details, still fully to explain the principle or general nature of the machine. It should serve to render very interesting to an attentive reader, a visit to any place where a steam-engine is in use. To avoid

complexity in the figure, the parts which the reader can easily conceive as the walls of the building and the framing of the machine are not here sketched.



612. 1st. The part which first claims attention is the great cylinder *c d*, already spoken of as the main portion of the machine, in which the *piston* P is moved up and down by the action of steam entering from the boiler, alternately above and below it, through the pipes *e c* and *e d*. The barrel or cylinder is bored with extreme accuracy, and the piston is padded or packed round its edge with greased hemp or other soft material, or has the metallic packing of iron rings which cause little friction, so as to be perfectly air or steam-tight.—2nd. The next part to be mentioned is the *boiler* B, which is made of suitable size and strength.—3rd. The steam passes from the boiler along the pipe to *e*, and there, by suitable *cock* or *valves*, worked by the engine itself, is directed alternately to the upper and under part of the barrel; and while it is entering to press on one side of the piston, the waste steam is allowed to escape from the other side, either to the atmosphere, for high-pressure engines, or into—4th, the *condenser* at C, for condensing engines; the condenser being always kept at a low temperature by cold water jetting into it and pumped out again by the piston *k*.—5th. *The supply of steam* from the boiler to the cylinder is regulated by a *throttle valve* placed somewhere in the pipe B *e*, and made obedient to what is called—6th, the *governor*, a contrivance not represented here, but already described at Art. 134, to illustrate centrifugal force. It consists of two balls hanging by rods jointed together like the legs of a tongs, from opposite sides of an upright

spindle, which is made to revolve by connexion with some turning part of the machinery:—when that spindle is turning at all faster than with the desired speed, the balls fly more apart, and thereby move the steam valve so as to narrow the passage; and on the contrary, when it turns more slowly than desired, they collapse, and by so doing open the valve wider.—7th. The *supply of water* to the boiler is regulated by a *float* on the surface of the water in the boiler; which float, on descending to a certain point, because of the consumption of water, opens a valve to admit more.—8th. There is a *safety valve* in the boiler, *viz.*, a well-fitted flap or stopper, held against an opening by a weight, which allows the valve to open whenever the steam acquires a certain tension, and before danger can arise from overheating of the water.—9th. The *rapidity of the combustion*, or force of the fire, may be exactly regulated by the state of the boiler and the wants of the machine in various ways: one of which is to have a small tube (not represented here) rising from the boiler, closed by a loaded piston, which, when the water in the boiler becomes too hot, and the steam therefore too strong, is caused to narrow a little the chimney-valve, or *damper:* the draught is then diminished and the fuel saved, until a brisker fire is again required.—10th. In this figure *a i g* marks the place of the *great beam*, turning on an axis at *i*, and transmitting the force of the piston to the working machinery. When the labour is to pump water, the pump-rods are simply connected with the end *g* of the beam, but when any rotatory motion is wanted, the end *g* is made to turn—11th, a *crank l n* by the rod *g l;* and uniformity of motion is obtained by the influence of—12th, the great *fly-wheel m* (Art. 348) fixed to the axis of the crank.

613. The smallest and simplest steam-engine, and therefore the cheapest, is that called the *high-pressure engine.* In it steam is used of great density, and consequently of great force, as of 50 lbs. or more to the inch; and while the fresh steam is admitted to press on one side of the piston, the steam which has already worked is allowed to escape, or is driven out to the air through a valve opened on the other side. The succession of semi-explosions seen and heard when a railway locomotive engine passes mark the escape of the used steam. The atmospheric resistance to the issue of the steam diminishes the working force of the piston just 15 lbs. per inch. The simplicity of this form of engine recommends it, but the danger of having

one large boiler of over-heated water seeking to escape, has led to the adoption in many cases of small boilers, consisting chiefly of strong tubes communicating with one another.

614. In the low-pressure engine with large boilers, steam may be used of force not exceeding 20 lbs. on the inch, which force is only 5 lbs. more than the atmospheric pressure, and would not require a boiler of great strength: but as the interior of the low-pressure engine is kept in a state of vacuum, except where the steam is acting, nearly the whole pressure of 20 lbs. is made available, and the engine has the same power, if of equal size, as a high-pressure engine working with steam of 35 lbs. on the inch. The required vacuum is preserved by means of a separate vessel or box, represented at C, called the condenser, into which a small stream of cold water is constantly rushing to condense the steam, and is afterwards pumped out with the condensed steam, and with any little air that may have entered: the pump is represented at *k* in the figure. Steam on coming in contact with a cold body is condensed almost with the rapidity of an explosion; and therefore the instant that opened valves make a communication between the cold condenser and any part of the engine containing steam, this rushes to the condenser, and becomes water, leaving a vacuum behind. The grand improvement by Watt was in the contrivance of this separate condenser, for, until his time, cold water had always been thrown directly into the working cylinder, cooling it so much, that twice or thrice its fill of steam was destroyed at each stroke to warm it again before it could work. This single change saved more than three-fourths of the quantity of fuel formerly expended.

615. Before Watt's day, the only steam-engine in use, and which was employed almost solely for pumping water, was a rude *single-stroke engine*, as it was called, in which steam, admitted under the piston to raise it, aided the weight of the pump-rods at the far end of the beam, and that steam being then condensed so as to leave a vacuum in the cylinder, the pressure of the atmosphere above pushed the piston down to do its work: on this last account the engine was also called an *atmospheric engine*. This engine wasted so much fuel, from causes of which the chief is mentioned in the last paragraph, that the expense was not much less than that of employing horses.

616. In this atmospheric engine, the steam which lifted the piston against the atmospheric pressure, required to be at least

as strong as that pressure, to the very end of the stroke. Another of Watt's great improvements was, his not allowing atmospheric air at all to enter the cylinder, and thereby maintaining always a vacuum on the side of the piston where steam was not working, by which procedure he not only avoided the cooling effect of the air, but was at liberty to shut off the steam, as it is expressed, or to stop the supply for each stroke, before the cylinder was full, and then to make the further expansion of the quantity admitted impel the piston to the end of the stroke. This principle of causing the mere farther expansion of a certain bulk of steam to do work was afterwards carried to a great extent by Messrs. Hornblower, Woolfe, and others, who constructed engines with two barrels, in the first and smaller of which the steam was made to act in its dense or strong state, as it issued from the boiler, and when it had finished a stroke there, instead of being at once sent useless to the condenser, it was admitted to a larger piston, which it moved by its continued expansion alone:—the same steam thus doing double work or more. Nearly all the advantages of the two cylinders, however, are obtainable from the single cylinder, as now used in most of the Cornish mines. Steam of about 60 lbs. pressure on the inch is admitted to the cylinder, until the piston is driven nearly one-third of its way, and the admission valve being then shut, that measure of steam is left to finish the stroke merely by its expansion. The pressure of the expanding steam gradually diminishes, it is true, in proportion as the volume increases; but in pumping water there is a great saving of time, from having the power more intense at the beginning of the stroke, when the vast mass of water and machinery has first to be put in motion. Steam while doubling its volume by mere expansion, will do about *two-thirds* as much work as while originally rising from the boiler, and by subsequent doublings, it might add to the effect of the first: the increasing size of the cylinder, however, and increased friction, confine this mode of using steam to moderate limits.

617. It might be supposed that high-pressure engines without condensers would be very wasteful, because in them the steam which has acted must be driven out of the cylinder against the powerful resistance of the atmosphere, while in the low-pressure engine it has instant access to the vacuum of the condenser, and so leaves effective the whole pressure of the fresh steam on the opposite side of the piston. But as in the low-pressure engine,

a considerable part of the power of the steam is expended in overcoming the friction and other impediments of the numerous and bulky parts, while in that of high-pressure, the parts are much fewer and smaller in proportion to the force exerted, the loss from friction, &c., is much less than might be expected.

618. From misapprehension of the law of increase of force by increase of heat in water, explained by the table at Art. 606, some exceedingly false conclusions have been drawn, and acted upon at great expense, as by the late Mr. Perkins, in attempts to make engines to work with an excessively high pressure. Besides making the error now alluded to and others, inventors overlooked the fact, that we possess no material for cylinders and pistons strong enough to bear the intensity of pressure, heat, and friction contemplated even for a moderate time. Perhaps more striking examples could not be adduced of the grave errors into which even highly ingenious men may fall, when not sufficiently attentive to the general truths of nature on which the arts which occupy them are founded, than in the history of supposed inventions and improvements connected with the steam-engine.

619. The fertile genius of James Watt did not stop at the accomplishment of the two or three important particulars described above, but throughout the whole detail of the component parts, and the management in various applications of the engine, he contrived prodigies of simplicity and usefulness. We should exceed the prescribed bounds of this work by entering more minutely into the subject; but we may remark that, in the present perfect state of the engine, it appears a thing almost endowed with intelligence. It regulates with perfect accuracy and uniformity the *number of its strokes* in a given time, *counting* or *recording* them moreover, to tell how much work it has done, as a clock records the beats of its pendulum;—it regulates the *quantity of steam* admitted to work;—the *briskness of the fire;*—the *supply of water* to the boiler;—the *supply of coals* to the fire;—it *opens and shuts its valves* with absolute precision as to time and manner;—it *oils its joints;*—it *takes out any air* which may accidentally enter into parts which should be vacuous;—and when anything goes wrong which it cannot of itself rectify, it *warns its attendants* by ringing a bell:—yet with all these talents and qualities, and even when exerting the force of hundreds of horses, it is obedient to the touch of a hand;—its aliment is coal, wood, charcoal, or other combustible;—it consumes none while idle;—it never tires, and wants no sleep;—it

is not subject to malady when originally well made; and only refuses to work when worn out with age;—it is equally active in all climates, and will do work of any kind;—it is a water-pumper, a miner, a sailor, a cotton-spinner, a weaver, a blacksmith, a miller, &c., &c.: and a small engine in the character of a *steam-horse* may be seen dragging after it on a railroad a hundred tons of merchandize, or a regiment of soldiers, with four times the speed of the fleetest coaches of old. It is the king of machines, and a permanent realization of the *Genii* of Eastern fable, performing supernatural feats at the command of man.

620. We need not wonder that the inventor of an engine having such qualities, should be deemed deserving of the highest honours which his fellow-men could bestow. In November 1825 a public meeting was held, to vote a monument to WATT, then recently deceased; and the most distinguished men of the empire, of all parties, philosophers, and statesmen, met to vie with one another in speaking his praise. Eloquent indeed were the discourses pronounced; but perhaps in the progress of civilization there can rarely be offered such motive and occasion. The common voice of that assembly scarcely exaggerated, when attributing to Watt's genius and perseverance that increase of our national commerce and riches and power which had enabled free Britain, almost single-handed, at an extraordinary crisis of human affairs, to contend with Europe combined against her, and at last to triumph, securing thereby her own well-being, and probably advancing that of the human race.

The explosion of gunpowder and of all fulminating mixtures bears so strong an analogy to the phenomenon of the formation of steam, that the student may advantageously contemplate the subject in this place.

621. The ingredients of which gunpowder is formed are chiefly substances which, when separate, exist, at any common temperature, in the form of air or gas; and ignition sets them all free or loose, with a production of still more intense heat, and an increase of volume which is instantaneous, and almost irresistible. By experiment and mathematical deduction, it appears that the exploding particles begin to separate from each other with such velocity as if a thousand volumes of air had been condensed into one volume: and this explains the corresponding force and swiftness with which a bullet is propelled.

622. The fulminating metals are chiefly combinations of the

like usually gaseous substances with metals; and the ingredients are held together by so weak a bond, that slight friction or elevation of temperature disunites them so as to produce the explosion more powerful than that of gunpowder.

The escape of condensed air from the chamber of an air-gun, is also a species of explosion; but is very gentle compared with that of gunpowder.

623. It has lately been shown that a gun-barrel may be connected with a high-pressure steam-boiler, in the same manner as with a chamber of condensed air; and as the steam may be generated continuously as long as water remains in the boiler, if bullets be allowed to fall into the barrel fast enough, a hundred or more may be thrown out every minute, with the same force and precision as if each issued from a common fire-arm. The rapid succession resembles the issue of water from a jet-pipe; and if such an engine could be brought to act in a field of battle, its barrel of death, made to point gradually along a line of men, would mow them down like corn-stalks before the scythe. The horrid idea and the proposal have been excused by saying, that to show the possibility of such destruction would have the effect of putting an end to war altogether.

624. The invention of gunpowder, with the consequent change of military tactics, because it gave to a handful of men possessing it the mastery over thousands who had it not, was hailed by the thoughtful men of the day as a certain security against the relapse of civilized mankind into such barbarism as followed the irruption into Europe of the Goths and Vandals:—only well-instructed and disciplined armies could now overrun a European kingdom. This consideration, however, has less interest, since the invention of printing, and other changes in the world, have afforded still better and more humane securities.

Besides the important instances above cited of the pressure of the atmosphere determining whether certain substances shall or shall not have the form of air, there are others now to be mentioned where the effect is modified by the mutual attraction of different kinds of substance.

625. The pressure of the superincumbent atmosphere at the surface of the earth forces a certain quantity of air into combination with water, so as to make it form part of the liquid mass. This air separates from the water, and reappears at once on

taking off the pressure. If we place a glass of common water under the receiver of an air-pump and then exhaust the receiver, the water is soon crowded with bubbles of air, seen adhering to the surface of the glass all around, or rising through the water. This admixture of pure air in union with water is necessary to the life of fishes. Such air is driven off by boiling, and hence the unfitness to support the life of fishes, and the vapid taste of water that has recently been boiled.

626. In the production of beer, wine, and other fermented liquors, there is formed, during the fermentation, some alcoholic spirit and a large quantity of the substance called carbonic acid. Much of this last flies off in its usual form of gas, but, because of the pressure of the atmosphere, much still remains in union with the liquid. On removing this pressure suddenly, the liquid appears almost to boil, as when a glass of warm beer is placed under the receiver of an air-pump, and the air is extracted.

627. A degree of pressure still greater than that of the atmosphere, keeps a proportionally larger quantity of this carbonic acid in liquid combinations; as in bottled porter or sparkling champagne before the confining cork is drawn; but as soon as the compression maintained by the cork is removed, the gas escapes, causing the thin champagne to sparkle, and the more viscid beer, which retains more strongly the little air-bubbles as they rise, to be covered with froth. After the sparkling or frothing have ceased under the atmospheric pressure, the phenomenon may be instantly renewed by placing the glass in the air-pump receiver.

628. Carbonic acid so readily becomes liquid when its attraction for water assists the compression used, that enough of it may be united with water to make a pint of water become a pint and a half of compound liquid. The soda water, or aërated water, now so generally used as drink in warm weather, is water with twice or thrice its bulk of carbonic acid forced into it by pressure; a part of this gaseous acid is seen beginning to escape at the instant of the cork being drawn.

629. Carbonic acid forms nearly half of the substance and weight of marble or lime-stone. When an acid with stronger attraction for lime, as vinegar or sulphuric acid, is poured upon marble, it dispossesses the carbonic acid, and unites itself with the pure lime. The carbonic acid in rising, constitutes the effervescence which then appears. Carbonic acid, for the manufacture of the common soda-water and other aërated drinks, is obtained from chalk or marble in this way.

630. Many mineral waters contain carbonic acid, which remains in tranquil combination while the water is bearing a certain pressure under ground, but which in part escapes as soon as the water issues to the air and has only the atmospheric pressure to bear: such waters are called sparkling waters.

631. The reason that champagne and the aërated waters are so cool when first decanted is, that their carbonic acid, in assuming its gaseous form, absorbs, as latent heat, a proportion of the sensible heat which was previously existing in the liquid.

The atmospheric pressure, by making the density of the air in any place dependent upon the height of the place above the level of the sea, causes corresponding differences of temperature.

632. The explanation of this is simple. If a gallon of air at the surface of the earth contain a certain quantity of heat, that heat is diffused equally through the space of the gallon; and if the air be then compressed into one-tenth of the bulk, there will be ten times as much heat in that tenth as there was before; an increase affecting the thermometer. In like manner, if by taking off pressure the gallon be made to dilate to ten gallons, the heat will be in the same degree diffused, and any one part will be colder than before. It is known that air may be so much compressed under the piston of a syringe, that the heat in it similarly concentrated, becomes intense enough to inflame tinder attached to the bottom of the piston: this device, under the name of the *match-syringe*, has been in common use for obtaining an instantaneous light.

633. Now, for the reason here explained, the air near the surface of the earth, forming the bottom of the atmosphere, because condensed by the weight of the air above it, is much warmer than if it were suddenly carried higher up, to where, from the pressure being less, it would be more expanded or thin. Accordingly the height of mountains may be estimated by the difference of temperature observed at the bottom and at the top. While a thermometer stands at 60° at the bottom of St. Paul's Cathedral in London, another marks only 58° at the top of the dome; and in the lofty ascent of a balloon, the thermometer soon falls to the freezing point and below it, the cold to the aëronaut becoming almost insupportable.

634. In every part of the earth, at a certain elevation in the atmosphere, different according to the latitude or proximity to

the equator, the thermometer is found to stand always below the freezing point. This limit in the atmosphere is called the line or level of perpetual congelation or of perpetual snow. In Norway it is at five thousand feet above the level of the sea; in Switzerland at six thousand five hundred; in Spain and Italy at seven thousand; farther south, at Teneriffe, at nine thousand; directly under the sun, as in Central Africa, and among the Andes in America, it is about fourteen thousand. We see, therefore, that snow-capped mountains exist near the equator as well as near the pole. It is this effect of elevation which renders many of the tropical regions of the earth not only tolerable abodes for man, but as suitable as any others; contrary to the opinion of the ancient philosophers of Europe, who deemed them, by reason of the great heat, an everlasting barrier, as regarded man, between the northern and southern hemispheres. Much of the tropical land of America is so raised, that, as to agreeable temperature, it rivals any European climate; while the lightness and purity of the air, and the brightness of the sun, add much to its charms. The vast expanse of high table-land within the empire of Mexico is of this kind, enjoying the immediate proximity of the sun, and yet, by its elevation of seven thousand feet above the level of the sea, possessing the most healthful freshness. The land in many parts has the fertility of a cultivated garden, and can produce naturally nearly all that the powers of vegetation fashion over the diversified face of the globe. The plains of Columbia, in South America, and others along the ridge of the Andes, are similarly circumstanced. The contrast is very striking, after sailing a thousand miles up the gentle slope of the river Magdalena, in a heat scarcely equalled elsewhere on earth, and surrounded by the animal and vegetable forms which can exist only in such a climate, at once to climb to the table-land above, where *Santa Fé de Bogota*, the capital of the republic, commands a view of interminable plains, that bear the livery of the fairest fields of Europe!

635. Persons not understanding the law which we are now illustrating, will express surprise that wind or air blowing down upon them from a snow-clad mountain, should still be warm and temperate. The truth is, that there is just as much heat existing in an ounce of the air on the mountain top as in the valley: but above, the heat is diffused through a space perhaps twice as great as when below, and therefore is less sensible. It may be the very same air which moves as a warm gale over a plain

at the foot of a mountain,—which then rises and freezes water on the summit—and which in an hour after, or less, is playing among the flowers of another valley, as warm and genial as before.

As the temperature in different parts of the atmosphere is influenced thus by the rarity of the air, and the rarity by the height, the vegetable productions of each distinct region or elevation are of a distinct character; and other peculiarities of place and climate acknowledge the same cause.

Because the atmospheric pressure determines the temperature of the air in different situations, as now explained, it has also a corresponding influence upon the state of aërial humidity, which is modified by the temperature.

636. It was explained at Art. 605 that water and other liquids under a vacuum, rise in the form of air or vapour, with force and in quantity having a strict relation to temperature—heat being in fact the cause of their rising; and the table at Art. 606 exhibits the force, and therefore the density of watery vapour corresponding to some certain temperatures. Now it is a remarkable circumstance, that vapour in the same quantity and of equal tension rises from any liquid, whether placed under the pressure of air, or where there is no air, with this difference, however, that through a space containing air it diffuses itself more slowly than if the air were not present. As regards the case of rising in air, it was for a long time supposed that the air dissolved the liquid as a liquid dissolves a salt; but it now appears that there is merely a mechanical mixture of the two gaseous fluids. If the vapour, while rising from a liquid, has not a tension or elastic force equal to the pressure of the atmosphere, the process is tranquil, and is called *evaporation*, and it goes on only as the vapour can diffuse itself among the particles of the air, and therefore slowly in air perfectly quiescent, but quicker as the air is moving more, or as the density of the air is less. But when the vapour, owing to greater heat, is strong enough to overcome the atmospheric pressure of fifteen pounds per inch, and the weight of any liquid over it, the phenomenon of boiling arises as already described.

637. For the reason now explained, the air of our atmosphere contains diffused through it a large quantity of invisible aëriform water; and if there were no intestine motions, and no changes of temperature in the atmosphere, the quantity of

water would soon everywhere reach a *maximum*, or would be the greatest that the temperature of the place could support: instead of this, however, from a variety of causes to be explained hereafter, the air is moving about constantly as winds, and the local temperatures are ever fluctuating, and when the temperature sinks, in a situation where a maximum of watery vapour is present, part of this is instantly reduced to the state of water again, and appears, according to circumstances, in the form of *mist*, *rain*, *snow*, or *hail;* while to supply material for these phenomena evaporation is going on wherever, over water, there is not a *maximum* of vapour in the air. These opposing operations of evaporation and condensation keep up that constant circulation of moisture which may be called a part of the life of nature.

638. When a given quantity of water assumes the aëriform state, it takes in and renders latent the same quantity of heat in all cases, *viz.*, six times as much as would heat the water from the freezing to the boiling point, whether rising, for instance, from a boiling caldron, or from the surface of a cool lake. Hence we see why evaporation is so cooling a process to any liquid or moistened solid from which it is rising: and as we have already shown that a rapid passing of dry air over such substance, or the placing it in a vacuum, quickens evaporation, we now see why both of these conditions accelerate the cooling. Wet linen placed in a strong wind, which does not contain a maximum of moisture, becomes dry almost immediately; a bottle of wine covered with a wet cloth and suspended in a current of air, as is practised in warm climates to prepare wine for the table, is quickly cooled; mats hung around the walls of houses in India, and frequently wetted through the day, preserve a pleasing freshness in the apartments. Sprinkling water or vinegar over a hot sick-room cools and refreshes it; and watering the streets of a city moderates in them the intensity of summer heat. In warm climates water is cooled for drinking by being put into vessels so porous that the external surface is always moist, the vessels being then suspended in a current of air, or during a calm being made to vibrate in the manner of a pendulum. Again, the rapidity of evaporation from water under the exhausted receiver of an air-pump, and particularly when some other substance which powerfully absorbs watery vapour is included in the receiver, is so rapid, and carries off the heat so quickly, that the mass of water freezes before much of it has

been carried away. This process is used for making ice in India.

639. It is partly because air saturated with moisture, that is to say, having as much water diffused in it as can be supported in the invisible or aëriform state at the existing temperature,—lets fall a part on any reduction of the temperature, that the air of any portion of the atmosphere which has been heated by the sun during the day, and has received much moisture, lets part of that fall again during the night, and exhibits the night fogs of certain seasons, which fogs float upon the surface of the earth, until again acted upon by the beams of the next morning's sun. Fog when farther condensed, by groups of the minute particles uniting, forms rain; and rain when cooled becomes snow or hail.

640. The quantity of dew which falls at night depends much on the quantity of moisture taken up by the atmosphere during the heat of the day; and the immediate cause of the dew is, as was ingeniously proved by Dr. Wells, that the temperature of the objects on which it settles has become lower during the night than that of the air around them, and than is required to maintain in the invisible state, the moisture in that air. There is a tendency in heat to diffuse itself uniformly among bodies, by a constant radiation from one to another, rapid in proportion to the differences of temperature. The earth's surface, therefore, during the day receives heat from the sun, shot through the clear atmosphere which absorbs little, and becomes comparatively hot, and during the night it gives out heat again by radiation towards the cold sunless sky, from which there is little or no return. When there are clouds in the atmosphere at night, they obstruct the upward radiation from the bodies on the earth's surface, becoming thus, as it were, a clothing to maintain the warmth of the earth beneath them,—and on cloudy nights there is little or no dew. Through a clear night sky the heat radiated upwards is diffused in space, and is lost altogether to the objects which emitted it. The objects, therefore, which during the day had a higher temperature than the atmosphere around, now become colder than it, and the aëriform water which comes in contact with them is condensed, and forms what we call dew. This beautiful provision of nature supplies the necessary moisture to vegetables during seasons when rain is deficient. Dew deposited on very cold objects freezes as it settles, and is then called *hoar frost.* A phenomenon which

may be classed with dew, is the perspiration, as it is vulgarly called, seen on massive walls and furniture, when with change of weather a warm moist air of higher temperature than the walls suddenly comes upon them. There is like result when a crowd assembles in a cold church, of which the walls or other solid objects then, from not having yet acquired the new temperature of the surrounding air, condense upon themselves a copious deposition of the breath moisture. For a similar reason a decanter of wine brought from a cold cellar or from an ice-pail, into a room with company, is soon covered with thick moisture or dew; as are the glasses also into which the cool wine is poured. It is still another phenomenon of the same kind when we see the moisture of warm breath condensed on any cold polished surface, as on the face of a mirror, or on the glasses of a carriage shut up, or on the windows of a room in winter. When the surface of a window pane is very cold, the moisture freezes on it with the appearance of beautiful arborescence.

641. Many instruments have been contrived, with the name of *hygrometers*, for indicating the quantity of water in the atmosphere. A prepared human hair forms part of one of those formerly used; the lengthening or shortening of the hair, according to the quantity of moisture absorbed into it, is caused to move an index like that of a wheel-barometer, to mark the degrees. This, however, and other common hygrometers, are only philosophical toys; but Professor Daniell, in his 'Meteorological Essays,' described a correct and simple instrument for the purpose, depending on the formation of dew as explained above. The explanation in few words is, that when the temperature of a body in the atmosphere falls below that at which the quantity of watery vapour in the air around it can be maintained in the aëriform or invisible state, dew forms on the body. The degree of heat at which this happens is called the *Dew-point.* His apparatus consists of a bulb of glass, containing only some ether, which can be cooled to any degree by being connected with another bulb to be enveloped in an evaporating liquid: when moisture begins visibly to settle upon the first bulb, its temperature is exhibited on a thermometer enclosed, and is the dew-point.

642. A great fall of the barometer marks a diminished pressure in the atmosphere around, with a consequent dilatation of the air and fall of temperature, as explained a few pages back; and if the air at such a time hold a maximum of moisture, a part of this must become visible as fog or rain. Thus a fall of

the barometer, a fall of temperature, and a fall of rain, often occur as associated phenomena.

643. Illustrating this by experiment, we find, that on the extraction of common air from the receiver of an air-pump, a thin cloud or mist generally appears in it with the first strokes of the piston:—the reason being that the still remaining air, because cooled by the rarefaction, absorbs heat from the invisible vapour in combination with it, and renders the water visible. The mist may then be removed by the continued action of the machine, or may be re-dissolved by the usual quantity of air being re-admitted.

644. We understand from this why rain happens much more frequently among mountains than on extended plains. When air saturated with moisture approaches a mountain ridge to rise over it, for every foot that it rises, it escapes from a degree of the pressure which it bore while lower down, and in then dilating, it becomes colder, and lets fall part of its moisture. It is the rain copiously produced in mountainous regions from this and other causes which constitutes the supply of the many rivers there, and which, with periodical changes of wind, occasions the extraordinary annual overflowing of such rivers as the Nile, the Ganges, &c.

645. Those who have visited the Cape of Good Hope, will recollect a striking phenomenon illustrative of our present subject, observed there when the wind blows from the south-east. Cape Town and the bay in which ships anchor are on the west side of the Cape. Beyond the city, as viewed from the bay, there is a mountain of great elevation, called from its extended flat summit, the Table Mountain. In general its rugged steeps are seen rising in a clear sky; but when the south-east wind blows, the whole summit becomes enveloped in a cloud of singular density and whiteness. The inhabitants call the phenomenon the spreading of the tablecloth. The cloud does not appear to be at rest on the hill, but to be rolling rapidly onward; yet to the surprise of the beholder, it never descends, for the snowy wreaths seen falling over the precipice towards the town below, vanish completely before they reach it, while others are formed on the other side to replace them. The reason of the phenomenon is this. The air constituting the wind from the south-east having passed over a vast extent of the southern ocean, comes charged with as much invisible moisture as its temperature can sustain. In rising up the side of the mountain it is rising in the

atmosphere, and is therefore gradually escaping from a part of the pressure lately borne; and on attaining the summit it has dilated so much, and has consequently become so much colder, that it lets go part of its moisture. This then appears as the cloud just described; but it no sooner falls over the brow of the mountain, and again descends in the atmosphere to where it is pressed, and condensed, and heated as before, than it is redissolved and disappears:—the magnificent apparition dwelling only on the mountain top.

646. When the elevation to which moist air is suddenly carried is very great, the fall of temperature is proportional, and the separating water becomes snow instead of rain. This phenomenon is remarkably illustrated by a great *Hero's* fountain, established in one of the salt mines of Hungary; during the play of which, the confined air in one place is so compressed, that on being suddenly released, it expands and cools enough to cause the moisture contained in it to come out, even in summer, as a shower of snow.

The foregoing reasoning explains why, along the sides of mountain ridges, clouds are generally seen floating at a certain height only, and therefore in strata nearly horizontal. The water is separated from the air at a certain temperature, which corresponds with the height, and above that height the air is at the time too dry and rare to have clouds. Very lofty summits are seen from a distance projecting much above the clouds, and the admirer of such scenery who climbs towards them, may have to contemplate the grand phenomena of the thunderstorm far beneath his feet. Teneriffe soars so sublimely, that the distant sailor not unfrequently mistakes the line of clouds hanging around its sides for the white streak which elsewhere indicates the cliffs and waves of the sea-shore.

Fluid support or floating, in air. (Read the Analysis, page 203.)

647. When it was explained under "Hydrostatics," that any body immersed in a fluid has its bulk and weight resisted or buoyed up with exactly the force which supported the quantity of the fluid previously occupying the same space, and therefore that the body will sink or swim, according as it is heavier or lighter than its bulk of the fluid, the reasoning was as applicable to the case of a body immersed in an air or gas as to that of a body immersed in a liquid.

648. We hence see why a body weighed in air appears lighter by the exact weight of its bulk of the air, than when weighed in an empty space or vacuum; and why, for the same reason, the jocular question, whether a pound of lead or a pound of cork is the heavier, is not truly answered by saying that they are of equal weight; for the cork is really the heavier, because when balanced in air, bulky cork is more supported or buoyed up than dense lead. A small weigh-beam having attached to its opposite ends pieces of cork and of lead which equipoise in the air, if placed under the exhausted receiver of an air-pump, quickly exhibits the cork preponderating.

649. As any liquid lighter than water, such as oil or spirit of wine, on being set at liberty under the surface of water, will rise, while any heavier liquid, such as brine, syrup, or sulphuric acid, will sink; and in both cases with force proportioned to the difference of specific gravities:—so we find, that in common air, a mass of hydrogen, or of hotter air, ascends, because specifically lighter; while oxygen, carbonic acid gas, or colder air, descends, because specifically heavier. This truth is strikingly exemplified in

650. *The Balloon,*

which is a large thin bag of varnished silk, generally shaped like a globe or egg, and filled with hydrogen gas, a fluid lighter than common air. It is made sufficiently large that the difference between its weight when so filled and that of an equal bulk of common air, may enable it to carry aloft the material of which it is constructed, with the aëronauts, and their apparatus. It is in principle like a bladder of oil immersed in water. A globe of thirty-five feet diameter has a capacity of nearly twenty-two thousand cubic feet. This quantity of common air weighs about *sixteen* hundred pounds, and the same quantity of hydrogen gas, of easily obtained purity, weighs only one-eighth of that, or *two* hundred pounds. Such a globe, therefore, being buoyed up, or supported in common air, with a force of sixteen hundred pounds, while if filled with hydrogen, it weighs only two hundred, will carry up into the sky fourteen hundred pounds of material and load.

The first balloon was exhibited by a man ignorant of what he was really effecting. Seeing the clouds float high in the atmosphere, he thought that if he could make a cloud, and enclose it in a bag, it might rise and carry him with it. Then

erroneously deeming smoke and a cloud to be of the same nature, he made a fire of green wood, wool, &c., and placed a great bag over it with the mouth downwards to receive the smoke. He soon had the joy to see the bag full, and when set free, ascending; but he understood not that the cause was the hot and dilated air within, which, being lighter than the surrounding cold air, was buoyed up; while the visible part of the smoke, which chiefly engaged his attention, was really heavier than the air, and was an obstacle instead of a help.

This arrangement, called the *hot air or fire balloon,* was afterwards better understood, and was used by aëronauts, until the more commodious and less dangerous modification called the balloon of hydrogen gas, or the *inflammable air balloon,* was substituted.

Since the modern introduction of gas lights, the *carburetted hydrogen* prepared for them is generally employed for filling balloons. It is considerably heavier than pure hydrogen, but is so much cheaper and more readily obtained, that aëronauts like better to make a larger balloon to suit it, than a smaller one which obliges them to prepare the other.—A thin paper bag, open at the bottom, filled with the hot air rising from a large lamp, is a miniature *hot air or fire balloon;* and a common soap bubble filled with hydrogen or carburetted hydrogen gas, is a little *inflammable air balloon,* which mounts rapidly.

There are perhaps few occasions on which a young person is more surprised and gratified than when beholding for the first time a balloon sailing high in the bosom of the air, and bearing a human being to regions far beyond what the soaring eagle has ever reached; while to the intrepid aëronaut himself the scene of a world displayed beneath him is unquestionably the grandest, except that of the starry heavens, on which mortal eye has ever been turned. To him even wide-spread London, the queen of the cities of the earth, and a little world within itself, when viewed from a great elevation in the sky, appears but as a dusky patch upon a map, with the far-famed Thames winding through it as a silvery line, and the magnificent temples and palaces scattered around, appearing only as darker points standing out of the general mist of buildings, in which nearly three millions of human beings reside.

651. The first aëronautic expeditions astonished the world, and endless reveries passed through men's minds of important uses to which the new discovery might be applied; but more

mature reflection, and now frequent trials, have shown that the balloon, while furnishing philosophers with the opportunity of making a few interesting observations in elevated regions of the atmosphere, is still of very limited utility. The French, under the Directory in 1796, attempted to use it in aid of military operations; but the scheme was soon abandoned. It has been thought of also as a means by which travellers might obtain some information respecting regions like the interior of Africa and Australasia; but nothing in this way has been accomplished.

Aëronauts while aloft have a limited power of making the balloon rise farther by throwing out part of the sand-ballast which they carry with them, or of making it descend by opening a valve at the top through which part of the hydrogen gas may escape, but they have no power of producing a lateral motion of any useful amount. The idea which still haunts the minds of some projectors that by wings or other means a balloon may be moved about in the sky as a bird flies, or as a ship is moved on the sea, is an extravagant delusion. To undeceive a person, however, who can have harboured such a notion, by proving its fallacy, would require a longer lesson than there is room for here.

652. A balloon which is only half full at the surface of the earth, becomes quite full when it has risen three miles and a half, because at that altitude, air from below doubles its volume on account of the diminished pressure. A balloon, therefore, if quite distended on first rising, must let air escape as it ascends, or it will burst: this is true also of the drum of the human ear under similar circumstances, and in a contrary way under the opposite circumstances of a person descending in a diving-bell.

The downy seeds of plants seen floating about upon the winds of autumn, are not lighter than air, but have so much bulk and surface in proportion to their weight, that the friction upon them of the moving air is greater than their weight, and carries them along. (See Art. 715.)

A sheet of thin paper, made in some degree to resemble a balloon, by its having a little weight, representing the hanging car, attached by threads from its four corners, is often seen rising at a street corner, to the delight of the boy who watches it. Its rise depends upon the irregular eddy winds or currents which the corner produces.

653. *The ascent of flame and smoke* in the atmosphere, affords other examples of a lighter fluid rising or being buoyed up in a heavier; for both these are merely hotter air rising in the midst of colder.

The phenomenon of flame is produced when the burning substance is already a gas or contains some ingredient capable, on being heated, of assuming the form of gas. This, on ascending, burns or combines with the oxygen of the atmosphere, with intensity of action sufficient to produce a white heat. It is because charcoal and coke have nothing in them thus volatile, that they burn without flame, appearing like red-hot stones. The flame of a lamp or candle is merely the oil, wax, or tallow gradually converted into gas by the heat, and allowed to burn as it is disengaged and rises. The same gas obtained by heating the oil, &c., in retorts or close vessels which exclude the atmosphere, and from which vessels tubes lead to suitable receptacles called gas-holders, is the common oil-gas used for illumination.

654. Smoke consists of all the dust and visible particles which are separated from the fuel without being burned, and are, moreover, light or minute enough to be carried aloft by the rising current of heated air; but all that is visible of smoke is really heavier than air, and soon falls again, as chalk-dust subsides in water. In the receiver of an air-pump, where a candle has been extinguished by exhausting the air, the stream of smoke that continues to pour from the wick after the exhaustion, is seen to fall on the pump-plate, because there is no common air present to support it.

655. *Chimneys* quicken much the ascent of hot air merely by keeping a column of it together. A column of two feet high rises or is pressed up with twice as much force as a column of one foot, and so in proportion for all other lengths; just as two or more corks strung together lengthwise, and immersed in water, tend upwards with proportionably more force than a single cork; or as a long spear of light wood, allowed to ascend perpendicularly from a great depth in water, acquires a velocity which makes it protrude for an instant above the surface, while a short piece under the same circumstances rises slowly merely to float. In a chimney where one foot in height of the column of hot air is one ounce lighter than the same bulk of the external cold air, if the chimney be one hundred feet high, the air or smoke in it is propelled

upwards with a force of one hundred ounces. In all cases, therefore, the *draught*, as it is called, of a chimney-flue, is increased by its length. The following facts are consequences of this truth.

In low cottages, and in the upper floors of houses, the annoyance of smoky rooms is much more frequent than where chimneys are longer.

657. If there are two fires in the same room, or in any rooms open to each other, which have chimneys of different lengths, and where the doors and windows are so close, that air to supply the two draughts cannot enter by them, the taller will overpower the shorter, and cause it to smoke into the room; just as the long leg of a syphon overcomes the short one, or as a long log of wood, held down in water by a cord passing from it round a pulley at the bottom to a shorter log also floating, will rise, and pull down the shorter log.

A long chimney, for the reasons above explained, causes a current of air to pass through the fireplace very rapidly, and it has the advantage also of acting more uniformly than any bellows or blowing machine. On these accounts, for fires of steam-engines, and many others, it is the means of blowing generally preferred. The importance of length in a chimney explains the remarkable appearance of many mining districts, and of towns, where steam-engines abound.

When we heap dying embers together, so that the hot air rising from among them becomes a mass or column of considerable altitude, this column has the effect of blowing them gently, and helps to light them up again. A piece of burning paper thrown upon the top of a half-extinguished fire, often makes it glow afresh, by causing a more rapid current of air to pass through it from below, towards the paper.

658. The action or draught, as it is called, of a chimney, influenced, as we have seen, by its length, depends also on the degree in which the air in it is heated, because that determines the dilatation, or comparative lightness, which occasions the ascent.

659. In what are called *open fireplaces*, as used in the sitting-rooms of this kingdom, a large quantity of air directly from the apartment enters the chimney above the fire, and mixes with the hot air from the fire itself. This mixture ascends more slowly than if only the hot air directly from the fire entered,

and in a proportion dependent on the degree of mixture. The effect of preventing a part of this colder air from entering, is seen when a board or plate of metal is suspended across the upper part of the opening of the fireplace, so as to narrow the entrance:—almost instantly a quicker action is produced below, and the fire begins to roar as if blown by a bellows. This means is commonly used to blow the fire instead of bellows, or to cure a smoky chimney, by increasing the draught. What is called a *register stove* is a somewhat kindred contrivance. It has a flap placed in the throat of the chimney, which serves to widen or contract the passage at pleasure. Being out of sight it is little understood by servants and others, and although it might be rendered useful, it is turned to little account—as will be fully explained in the chapter on HEAT.

In what are called *close fireplaces*, as those of steam-engines, or brewers' coppers, when the furnace door is shut, no air can enter the chimney but directly through the fire: hence the action of such chimneys is very powerful.

660. In a room with two fires, or in drawing-rooms communicating with each other, although the chimneys are of equal length, that one over the strongest fire, or which has the chimney best arranged, will act the most strongly; and if the doors and windows of the apartment be so close as to prevent a sufficiency of air from entering by them to supply both fires, cold air will enter by that chimney which has the weakest action, and the smoke from it will spread into the room. How often is an assembling dinner-party annoyed by the smoke of a second drawing-room fire, lighted shortly before their arrival, and which had therefore to contend with the antagonist fire, already in powerful action all the day. While only one fire was lighted, the cold chimney was admitting the air to feed it, nearly as an open pane in the window would have done. A room may be made so close, that no fresh air can find entrance, and in such a case the smoke produced by its fire must all remain in the room.

661. When all the windows and doors of a house fit so closely as not to admit sufficient air for the acting chimneys, part of the supply for these comes down the chimneys that are not in use. Inattention to this fact often causes good chimneys to be deemed bad, because on the attempt being made to light a fire in them, the smoke first formed is thrown back by the descending current of fresh air. The fact is, that at the time when the servant

begins to light the fire, there is a downward current in the chimney, repelling, therefore, any heated air and smoke that approaches it, and for a time spreading that over the whole house. Were the room door in such a case to be shut for a few minutes, so as to cut off communication with the other *drawing* chimneys in the house, while at the same time the window were opened a little, the chimney would act at once; and when sufficiently heated, would continue to act as perfectly as any other.

There are some cases of smoky rooms not to be so easily corrected as those we have now mentioned. When a low house adjoins a lofty house, the wind blowing towards the latter, is obstructed and becomes a gathering or condensation of air against the wall; and if the top of a low chimney be there, the compressed air enters it, and pours downwards. The same happens occasionally in a degree from the proximity of high trees or rocks. In such cases, to avoid the evil, the low chimneys have to be made higher. Again, whenever, from the position of buildings, eddies of winds occur, or unequal pressures, as happens often at street corners, &c., the chimneys around do not act regularly. It is proverbial, that corner houses, or those at the ends of a row, are smoky houses; and we often see the desired uniformity of architecture in a street destroyed by the lengthening of the chimneys of the houses at the extremities.

662. When smoke is found descending into a room where there is no fire, its empty chimney is at the time serving as an inlet for air to the house, and while the smoke of some neighbouring chimney is passing closely over the top of it.

663. In summer, when fires are not in use, there is often a strong smell of soot perceived in some of the apartments during the day, but which ceases at night. The explanation is, that during the day the chimney flue is colder than the external air, and by condensing the air which enters it, causes a downward current through the soot. During the night, again, when the external air becomes colder owing to the absence of the sun, the chimney, by retaining the heat absorbed during the day, is hot enough to warm the air in it, and to cause an upward current. These currents, in chimneys left open during the days and nights of summer, are almost as regular as the land and sea breezes of tropical countries.

These remarks prove how important it is to be able to conceive clearly of the motions going on, according to the simple

laws of matter, in the invisible air around us. Were such subjects better and more generally understood, many prevalent errors in the arts of life, influencing much the comforts and health of the community, would soon be corrected.

If we are filled with admiration on discovering how perfectly the simple law of a lighter fluid rising or being buoyed up in a heavier, provides a constantly renewed supply of fresh air to our fires, which supply we should else have to furnish by the unremitted action of some expensive blowing apparatus; still more must we admire that the operation of this law should effect the more important purpose of furnishing the ever-renewed supply of the same vital fluid to breathing creatures. The air which a man has once respired becomes poison to him; but because the temperature of his body is almost everywhere higher than that of the atmosphere around him, as soon as he has exhaled or discharged any air from the lungs, it ascends completely away from him into the great purifying laboratory of the atmosphere, buoyed up by new and fresh air which takes its place. No art or labour of his, as by the use of fans or punkas, could have done half so well what this simple law unceasingly and invisibly accomplishes, and accomplishes without effort or even attention on his part, and in his sleeping as in his waking hours. The heart must be cold which can think over all this without emotion.

664. *The art of ventilating and warming houses*

is one of vast importance. It is founded chiefly on knowledge of the movements produced in masses of air by changes of temperature, &c., as treated of in the present section, and on knowledge of the nature of combustion and the management of heat in various applications. It will therefore fall to be considered in the fourth part of this work, of which the title is HEAT.

665. *Winds or currents in the atmosphere*

are also phenomena, in a great measure dependent on the law, that lighter fluids rise in heavier. As oil let loose under water is pressed up to the surface and swims, so air near the surface of the earth, when heated by the sun, rises to the top of the atmosphere, and spreads there, forced up by the heavier air around. This heavier air tending inwards, constitutes the wind felt at the surface of the earth. The cross currents above and below in

the atmosphere, caused as now described, are often rendered evident by the motion of clouds or balloons.

If our globe* were at rest, and the sun were always beaming over the same part, the earth and air under the sun would become exceedingly heated, and the air would there be constantly rising like oil in water, or like the smoke from a great fire, buoyed up by currents or winds pouring from all directions below towards the central spot. But the earth is constantly rotating or turning round under or before the sun, so that the whole middle region or equatorial belt may be called the sun's place: and therefore according to the principle just laid down, there should be over that, a constant rising of air and high overflow towards the poles, and constant currents of colder air from the two sides, or the north and south, forcing the ascent. Now this phenomenon is really going on, and has been going on ever since the sun warmed the earth, producing the steady inferior winds of the northern and southern hemispheres, called *trade-winds*, on which in most places within thirty degrees of the equator, mariners reckon almost as confidently as on the rising and setting of the sun himself.

666. The trade-winds, however, although in truth moving from the polar regions towards the equator, do not appear on the earth to be directly north and south, for the eastward whirling, or diurnal rotation of the earth, causes the wind from the north to appear on the surface of the earth as if coming from the north-east, and the wind from the south as if coming from the south-east. This fact is illustrated by the case of a man on a galloping horse, to whom a calm appears to be a strong wind in his face; and if he be riding eastward, while the wind is directly north or south, such wind will appear to him to come from the north-east, or south-east:—or again, is illustrated by the case of a small globe made to turn upon its axis set vertically, while a ball or some water is allowed to run from the top of it downwards;—the ball or water will not immediately acquire the whirling motion of the globe, but will pass also slantingly downwards, in a track which, if marked upon the globe, will appear not as a direct line from the axis or pole to the equator, that is from north to south, but as a line falling obliquely. Thus then, the whirling of the earth is the cause of the oblique

* The facts of the globular form and rotation of this earth are fully explained in the chapter on Astronomy.

direction towards the west of the trade-winds, and not, as has often been said, the sun drawing them after him.

The reason why the trade-winds at their external confines, which are about 30° from the sun's place on either side of the equator, appear *north-east* and *south-east,* and become more nearly *east* as they approach the central line, is, that at the confine they are like fluid coming from the axis of a turning wheel towards the circumference, but which has not yet acquired the velocity of the circumference; while, nearer the equator, they are like the fluid after it has for a considerable time been turning near the circumference, and has acquired the rotary motion there.

667. While, in the lower strata of the atmosphere, air is thus constantly flowing towards the equator and forming the steady trade-winds between the tropics, in the upper regions there must of course be a counter-current distributing the heated air again over the globe: accordingly, since reasoning led men to expect this, many striking proofs have been detected. At the summit of the Peak of Teneriffe, observations now show that there is always a strong wind blowing in a direction contrary to that of the trade-wind on the face of the ocean near its base. Again, the trade-winds on the sea among the West-India Islands are constant from the east, yet volcanic dust thrown aloft far to the west over the island of St. Vincent, in the year 1312, was found, to the surprise of the inhabitants of Barbadoes, hovering over them in thick clouds, and falling, after coming more than 100 miles directly against the strong trade-wind. Persons sailing from the Cape of Good Hope to St. Helena with a fair trade-wind from the south-east, have often to remark that the sun is hidden for days together, by a stratum of dense clouds passing in the contrary direction high in the atmosphere; which clouds consist of the moisture raised near the equator with the heated air, and becoming condensed again as it approaches the colder regions of the south.

668. Beyond the tropics, where the heating influence of the sun is less, the two great, general, contrary currents of the heated air above, overflowing from the equatorial or tropical regions towards the poles, and of the colder air below flowing from the polar regions to the equator, become gradually less distinct. The polar layer, having to cover the widening bulge of the globe towards the equator, breaks into gaps, which the higher layer,

being in a corresponding degree compressed as it reaches narrower longitudes, plunges down to fill, and there follow consequently, mixture, contention, and stormy eddies. The winds of the temperate climates are, in consequence of this, described as *variable* winds. Still, as a general rule, when air is moving towards the equator from the polar regions, where the rotation of the earth makes but a slow motion of the surface from west to east, which motion is shared by the atmosphere of the parts, the air must, in coming nearer to the equator, have the appearance of an east wind, or a wind moving in the contrary direction to that of the surface of the earth itself, until it gradually acquire the rotation speed of that part of the surface of the earth on which it is found; and again, when air is moving from the equator, where it had at last acquired nearly the same rapid motion as that part of the earth, namely, of more than a thousand miles in the hour, on reaching parts nearer the poles, which have less eastward motion, it continues to run faster than they, and appears as a west wind. In many situations beyond the tropics the west winds, which are merely the upper equatorial currents which have descended, are almost as regular as the easterly winds within the tropics, and might also be called trade-winds:—witness the usual shortness of sailing voyages from New York to Liverpool, and the length of those made in the contrary direction. North of the equator, then, true north winds appear to be north-east, and true south winds appear to be south-west:—which two are the winds that blow in England for three hundred days of every year. In southern climates the reverse is true.—This subject will be resumed under the head of rotation of the earth, in ASTRONOMY.

669. While the sun is beaming directly over a tropical island, he warms very much the surface of the soil, and therefore also the air upon it; but the rays which fall upon the ocean around penetrate deep into the mass, and produce less increase of superficial temperature. As a consequence of this, there is a rapid ascent of hot air over the island during the day, and a cooler wind blowing towards its centre from all directions. This cool air constitutes the refreshing *sea-breeze* of tropical islands and coasts. A person must have been among these, to conceive the delight which the sea-breeze brings after the sultry stagnation which for a time precedes it. The welcome ripple shorewards is first perceived on the surface of the lately smooth or glassy sea; and soon the whole face of the sea is white with

little curling waves, among which the graceful canoe, lately asleep on the water, shoots swiftly along.

During the night a phenomenon of opposite nature takes place. The surface of the earth, then no longer receiving the sun's rays, is cooled by radiation upwards, while the sea which absorbed heat during the day, not on the surface only, but through its mass, continues to give out heat all night. The consequence is, that the air over the earth becoming colder than that over the sea, sinks down, and spreads out on all sides, producing the *land-breeze* of tropical climates. This wind is often charged with unhealthy exhalations from the marshes and forests, while the sea-breeze is all purity and freshness. Many islands and coasts would be scarcely habitable but for the sea-breeze.

670. The peculiar distribution of land in the Asiatic part of the globe, produces the notable effect there of a sea-breeze of six months, and a land-breeze of six months. The great continent of Asia lies chiefly north of the line, and during its summer, the air over it is so much heated, that there is a constant steady influx from the south—appearing south-west, for the reason given in a preceding page; and again during its winter months, while the sun is over the southern ocean, there is a constant land-breeze from the north—appearing, for a like reason, north-east. These winds are called *monsoons;* and if their utility to commerce were to be a reason for a name, they also might have been called trade-winds. In early periods of navigation, they served to the mariner the purpose of compass, as well as of moving power; and one voyage outward, and another homeward with the changing monsoons, filled up his year.—On the western shores of Africa and America also, the trade-winds are interfered with by the heating of the land; but much less than in Asia, and always in accordance with the laws now explained.

The frightful tornadoes, or whirlwinds, which occasionally devastate certain regions, making wrecks of many a ship caught on the waters, and frequently also of structures on land, and the shorter gusts or squalls and waterspouts met with everywhere, involve some sudden electrical changes in the atmosphere, not yet fully explained.

671. There are few families in this kingdom now which have not members residing in some of our tropical colonies, where the great heat and moisture quicken the decomposition of dead organic substances, animal and vegetable, and so produce the

poisonous malaria which occasions the fevers and other diseases destructive to colonists from Europe. A means of guarding against the evil is therefore highly important; and such security is suggested in considering the phenomena of land and sea breezes here described, and of the formation of dew, described in Art. 640.

It is generally known that in approaching Rome across the wide marshy flat called Campagna di Roma, persons who are by any accident detained and obliged to pass the night there, at certain seasons of the year, will probably catch the fever of the place, and may die. During the day there is no danger. The like occurs in many other localities of similar nature. Vera Cruz and its neighbourhood on the American coast, where persons from Europe generally disembark on their way to Mexico, and may pass nights, is still more dangerous. Many places on the coast of Africa, such as Sierra Leone, the mouths of the river Niger, and others, are notorious in the same way. Of Asiatic coasts nearly the like has to be said. Rangoon, Bencoolen, and others recall sad histories. When the Dutch first settled in the rich island of Java, they chose, as the site of their future city Batavia, a level, humid plain, where they might conveniently construct canals in the streets, as was practised in their home cities of Amsterdam, Rotterdam, &c. They soon found, however, that mortality from malarial fever was great among those who passed their nights on the low level, while those who had their dwellings on the neigbouring dry heights were safe. At present business is transacted during the day in the town, but all who can, sleep at a distance. Even in northern Europe there are kindred facts. People still think with pain of the Walcheren fever, so fatal to the armament sent there in 1809. In the low fen districts of England, notwithstanding the improved draining now practised, agues are still common.

Of all this the explanation is, that on the damp surface of the earth the decomposition of animal and vegetable remains goes on actively day and night, producing hurtful malaria. But during the day the sun's rays shot through the transparent air, lose little of their heat, although the air above the level of the line of perpetual snow (Art. 634) is much colder than ice, and warm the surface of the earth. This then by contact warms the air lying upon it, and causes that to rise and carry away the malaria then formed. During the night, on the contrary,

the earth receiving no heat from the sunless sky, radiates away into cold void space the heat which it had received during the day, and becomes colder than the atmosphere above it. The consequence is, that the malaria formed during the night is cooled, and rendered so heavy that it does not rise but accumulates on the surface of the earth as a poisonous layer, destructive to those who breathe it.

Precautionary measures suggested by knowledge of the facts above detailed, of which some one is likely to be at the command of every person so circumstanced as to require it, are—

(1.) Not to pass the night in dangerous situations.

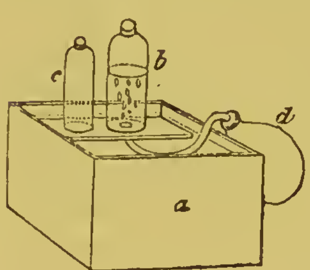
(2.) If that is unavoidable, then to sleep in the upper rooms of the house.—In ague-districts of England persons who sleep near the top of the house often escape.

(3.) To use simple means, such as described here in the chapter on VENTILATION, to keep the sleeping-room supplied with purer air from above.

672. *The Pneumatic Trough and Gasometer*

of the chemist are contrivances constantly displaying the truth now under consideration, "that a lighter fluid is buoyed up and floats on a heavier." They are important parts of the apparatus for operating on substances existing in the form of air.

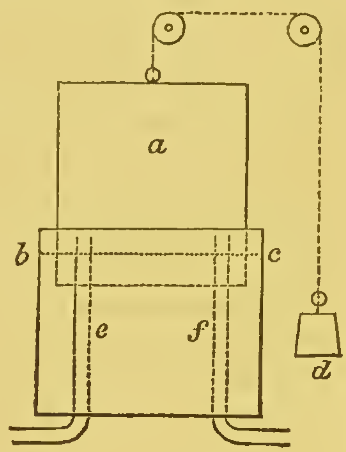
The trough *a* may be made of metallic plate, or of wood lined with metal, and of any convenient size. It is nearly filled with water, and has at one end about an inch under the surface



of the water, a shelf, on which jars or vessels, as *b* and *c*, may rest with the mouth downwards in the water. Any particular air or gas is preserved separate from the atmosphere, by being confined in one of these jars. The gas is passed into the jar by the operator first immersing the jar in the trough, to expel the common air from it and fill it with water; then by placing its mouth over an opening in the shelf, and causing the gas to rise there from another vessel or pipe *d*. That letter indicates a long-necked vessel, used to contain the ingredients for the production of gases by chemical action. The gas of course rises to the top of the jar *b*, and gradually displaces the water. During the operation of filling, the jar rests on the shelf, and the gas is allowed to rise into it through a hole in the shelf,

provided with a small funnel gaping downwards to catch the gas more readily. The shelf may have room on it for many jars, and it may have more holes than one; and if the gas under operation be such that water absorbs or changes it, some other liquid, as mercury, may be used to fill the trough instead of water.

673. A *gasometer* or *gas-holder*, is merely a larger jar or vessel, as *a*, dipping into water, with its mouth downwards, in a trough of its own shape, *b c*, and so supported or counterpoised by a weight at *d*, over pulleys, that very little force suffices to move it up or down. Air forced into it through a pipe *f* opening under it, causes it to rise or float higher in proportion to the quantity. The air is made to pass from it again when wanted, either through the same tube or through another as *e*.



The huge gasometers, exceeding in size an ordinary house, and containing the supply of gas for the lamps of a town, are vessels suspended as above represented, in great pits or troughs, filled with water. The gas issues with force proportioned to the downward pressure of the containing vessel, which may be nicely regulated in a variety of ways, and is generally made to equal the action of a column of water two inches in height; that is to say, such, that a pipe issuing from the gas-holder, and dipping into water at its other end, shall allow gas to escape, if immersed less than two inches perpendicularly.

It would be encroaching on the province of the chemist to treat here particularly of the substances which most generally exist in the aëriform state; but to give an increased interest to the description of the gas apparatus, a few leading facts may be mentioned.

674. Of about sixty-three distinct substances at present known as the materials of our globe, six, when uncombined and under common circumstances of heat and pressure, exist as airs or gases. The common substance *water* is a compound of two of these gaseous substances, *viz. oxygen* and *hydrogen*. By directing an electrical current through water, it is gradually decomposed, and from one side, a stream of aëriform oxygen may be received, and from the other a stream of hydrogen; the bulk of the latter

being just double that of the former. The two gases may be again united to form water, by mixing them in a proper vessel, and passing an electric spark through them. They combine with explosion.

675. This *oxygen*, so called from its relation to acids,* has been accounted, for many reasons, the most important simple substance in nature. It forms eight-ninths, by weight, of the ocean; one-fourth of the atmosphere; and, perhaps, one-fourth of the solid matter of the globe: possibly, therefore, although most persons think of it only as an air or gas, only a very small part of the quantity of oxygen in the world exists as air. It unites readily with most other substances, and generally with such intense action as to produce the phenomenon of fire or combustion;—the word *combustible* chiefly applies to substances which quickly combine with oxygen.

Oxygen assumes a singular variety of character in its different combinations. Thus with *hydrogen*, it forms water; with *lead*, it forms the substance called *red-lead;* mixed with *nitrogen*, in the proportion of about one to five, it forms *atmospheric air;* chemically combined in another proportion, it forms the *nitrous oxide*, or what is called the *laughing gas;* in a third proportion it forms the acid called *nitric*, or *aqua fortis;* with sulphur, it forms the *sulphuric acid* or *oil of vitriol;* with iron, and all metals, it forms their ores called oxides; and so forth. But the most important character in which we know it, is as that ingredient of our atmosphere, without which animals and vegetables cannot live, and fire cannot burn. Oxygen, from this part of its history, was long named *vital* or *pure air.*

Pure oxygen in the state of air is a little heavier than common air; but when holding a quantity of charcoal in solution, it forms aëriform *carbonic acid*, which is nearly twice as heavy as common air, and may be poured out of one vessel into another like water. Carbonic acid is what issues from soda-water, brisk ale, champagne, &c. while they sparkle. If drawn, unmixed, into the lungs in breathing, it is fatal to life. A charcoal fire left in a close room with sleeping persons, is soon fatal to them, because carbonic acid gas is the product of the combustion. So likewise, houseless wretches in winter, lying down in a brickmaker's field under shelter of a burning heap of bricks, often fall asleep for ever. The famous *Grotto del Cane*, in Italy, is a cavern always full of carbonic acid, which springs into it from below, as

* οξυς, acid, and γενναω, to generate.

water springs into a well, and runs over the brim like water from a well:—it received its name from the fact that a dog dies instantly when thrown into it. Carbonic acid rising in fermentation has often proved fatal to persons leaning over the edge of fermenting vats. It is common to see a rat fall dead, in the attempt to run along a plank laid across the mouth of a fermenting tub.

676. *Hydrogen,* the other ingredient of water, and so called from its relation to *water,** when in the state of air, is sixteen times lighter than oxygen. With it balloons are filled. When it holds in solution a certain quantity of carbon or charcoal, it becomes the common gas (carburetted hydrogen) used for illumination, and is the fire-damp of mines, of which the burning and explosion are so terrible. It forms one ninth, by weight, of the ocean, and is a considerable part of animal and vegetable bodies.

677. *Nitrogen,* so called from its relation to *nitric acid,* is the third and last substance which we shall mention. It is what remains of the atmosphere when the oxygen is removed. It forms about four-fifths of the atmosphere, one-fourth of animal flesh, and is found in small quantities in other combinations. It will not support life by itself, and therefore formerly was called *azote*:† with a larger proportion of oxygen it forms *nitric acid* or the *aqua fortis* of old.

The last few paragraphs may serve to show how many of the manipulations of chemistry are directed by the principles of physics or mechanical philosophy; and therefore how essential to the chemist the preliminary study of physics becomes.

* ὑδορ, water, and γεννaω, to generate.

† α, priv., and ζωη, life.

PART III.

ON THE PHENOMENA OF FLUIDS.

(CONTINUED.)

SECTION III.—HYDRAULICS—PHENOMENA OF FLUIDS IN MOTION.

(*Read the Synopsis, page* 1.)

ANALYSIS OF THE SECTION.

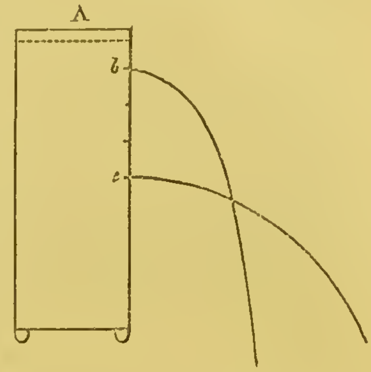
Whether the particles of matter exist in the form of solid, liquid, or air, the circumstance does not affect their properties of INERTIA *and* GRAVITY. *Hence liquids and airs, in proportion to their quantity, resist, receive, and impart motion, and have weight and friction, as is true of solids. This is seen in the phenomena of*

1. *Fluids issuing from vessels, or moving in pipes and channels.*
2. *Waves.*
3. *Fluids resisting the motion of bodies immersed in them; or themselves moving against other bodies.*
4. *Fluids lifted, or moved in opposition to gravity.*

"*Fluids issuing from vessels, or moving in channels.*"

678. There is a fact which to commencing students appears paradoxical, or not reconcileable with common previous knowledge, which yet when explained is clearly apprehended, and then serves to render intelligible many other important phenomena in hydraulics, usually deemed obscure. It is, that the force required to drive a certain quantity of water through a certain opening in a certain time must be increased fourfold

instead of twice to drive double the quantity through the same or a like opening in the same time. Thus if in a vessel of water A a small hole be pierced, in the side at *b*, a foot below the surface of the water, the pressure of that one foot in depth will cause a certain quantity, say a gallon, to spout forth in one minute; but if it be then desired to cause two gallons to issue in the same time from a similar opening below, that opening must be made not at two but at four feet below the water surface. Again, if a quantity of water be squirted from a syringe, or force-pump, by a force of one pound pressing the handle of the piston, a force of four pounds would be required to double the quantity of the discharge in the same time.



The reason of such facts is, that the double number of water particles moved or having their inertia overcome, would require double force if they were moved with only the same velocity; but because twice as many have to pass through the same sized opening in the same time, each must move with double speed, requiring another doubling of the force on that account, and the two doublings make a fourfold increase. The same reasoning explains the ascertained fact, that in such a case to force a triple discharge the power employed must be nine times as great, to force a quadruple issue it must be sixteen times as great, and so forth in the proportion of squares.

679. Another phenomenon illustrating the same principle is that if a tube be screwed into the lower part of a water cistern B, and have its outer end turned up as a spouting nozzle *c*, the water will jet upwards to the height of the water surface in the cistern, with a certain deduction for the resistance of the air and friction. Now, as a body shot upwards to any height has that velocity in departing, which it again acquires by falling back to the same place or level (with a certain deduction for the resistance of the air), as explained at page 65, it follows that fluid issues from any orifice in a reservoir with velocity equal to what a body acquires in falling as far as from the level of the fluid surface in the

reservoir to that of the orifice. By referring then to the law of falling bodies, as explained at page 63, we may learn the velocity of the issue of water from the side or bottom of a reservoir in any case, and therefore nearly the quantity delivered by an opening of a given magnitude.

680. It is a curious fact respecting discharging orifices in vessels with thin sides, that more water issues from such vessel through a short pipe, than through a simple aperture in the thin side of the same diameter as the pipe,—and still more if the pipe be funnel-shaped within, or a little wider towards its inner extremity. The explanation is, that the issuing particles coming from all sides of the opening to escape, cross and impede one another in rushing through a simple opening, as proved by the narrow neck called the *vena contracta*, which the jet exhibits a little beyond the opening; but in a uniform tube, this narrowing of the jet could not happen without leaving a vacuum around the part, and the pressure of the atmosphere, resisting the formation of such vacuum, causes a quicker flow. The funnel-shape again leads the water by a more gradual inclination to the point of exit, and considerably prevents the crossing among the particles which retards; besides that, because its external mouth surrounds the narrow neck of the jet, that part may be deemed the commencement of the jet.

681. Another remarkable effect of atmospheric pressure on such running liquids is, that if the channel be a tube of considerable length descending from a reservoir, it much quickens the discharge. Water naturally falls like any other body with accelerating velocity; but if it so fall in a tube which it fills like a piston, either portions of it below must outstrip what is above, leaving vacuous spaces between, or water from above must be pressed more powerfully into the tube by the atmosphere to prevent a vacuum. The resisting atmospheric pressure below is at the same time lessened by the weight of the water in the tube, and thus also the discharge is quickened. The increased forcing in by the atmosphere of the water at the top of the tube causes that depression of the water-surface in the reservoir over the tube, which becomes very conspicuous as the depth in the reservoir diminishes.

682. The friction or resistance which fluids suffer in passing along pipes is much greater than might be expected. It depends partly on the cohesion of the particles among themselves, and to the surface of the pipe, but more on friction and

on the particles near the tube being constantly driven from their straight course by the irregularities in its surface. A tube of an inch diameter and two hundred feet in length, placed horizontally, is found to discharge only a fourth part of the water which escapes by a simple aperture of the same diameter.—Air also in passing along tubes is much retarded. A person who erected a great bellows at a waterfall, to blow a furnace two miles off, found that his apparatus was almost useless. When gas-lights were first proposed, some engineers knowing this feared that the resistance from friction to the passing gas would be fatal to the enterprise. This was a groundless fear.

683. Higher temperature in a liquid increases remarkably the quantity discharged by an orifice or pipe,—apparently by diminishing that cohesion of the particles among themselves which exists in certain degrees in all liquids, and affects much their internal movements. The addition of 100 degrees of heat will in certain cases nearly double the discharge.

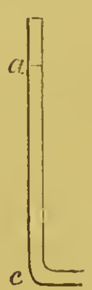
684. The flux of water through orifices under uniform circumstances is so steady, that before the invention of clocks and watches, it was employed as a means of measuring time. The vessels were called *clepsedræ.* That of Ctesibius is famous, in which the issuing water took the form of tears from the eyes of a standing figure deploring the rapid passing of precious time; and these tears being received into a fit vessel, gradually filled it up and raised another floating figure, who pointed to the hours marked on an upright scale. This vessel was daily emptied by a syphon, at the moment when the water reached a certain height, and the discharge of the water worked machinery which told the month and the day.—The common hour-glass of running sand is another modification of the same principle, with this remarkable difference, however, that increased depth of the sand does not quicken the flux.

685. The progress of water in an open irregular conduit, such as the channel of a river, is influenced by friction, still more than in close pipes. But for this, a river drawing its waters from an elevation of only 1,000 feet above the level of its mouth, would pour them out, with the velocity of water issuing from the bottom of a reservoir 1,000 feet deep; that is to say, at the rate of about 170 miles per hour. An ordinary flow of rivers is from three to five miles per hour, and their channels slope from three to five inches per mile.

686. If a sloping channel be connected with a reservoir of

water, so that by opening a sluice at the junction water may enter and completely fill the channel, the stream will gain speed as it flows, descending like a ball rolling down an inclined plane; and if the slope is considerable, the stream at a moderate distance will have double speed, causing the channel to be only half full. It is evident that two such channels might meet and the contents of both would then only fill a single channel of the same size. In cases of covered drains or pipes, persons not reflecting on the effect of increased declivity and increased speed have been surprised to see how small a drainage pipe can carry off a large quantity of fluid. This explains also why a mountain stream having various degrees of declivity in different parts may appear of strangely different size to persons travelling along its course.

687. The velocity of an open water current may be ascertained by immersing in it an upright tube, of which the bottom bent at right angles becomes an open mouth turned towards the stream. The water in the tube will stand above the surface of the stream, as much as would be necessary in a reservoir, according to the explanation given above, to cause a velocity of jet equal to that of the stream. A modification of this contrivance may be made to measure the force and velocity of the wind. A more obvious mode of telling the velocity of an open stream, is to observe with a stop-watch the progress of any floating body where it can be followed for a certain distance; and knowing the medium speed and the depth and width of the channel, the quantity delivered in a given time becomes a matter of simple calculation. The speed of the wind may be ascertained by observing how long the shadow of a cloud takes to pass across a field of known dimensions.



688. The friction of water moving in water is such, that a small stream directed through a pool, with speed enough to rise over the opposite bank, will soon empty the pool. The friction between air and water is also singularly strong, as is proved on a great scale by the magnitude of the ocean-waves, which are consequences of it; and on a small scale by the amusing experiment of making a light round body dance or play upon the summit of a vertical water-jet,—a chief cause of its remaining there being, that the current of air which rises around the jet by reason of the friction, presses the body inwards again, whenever it inclines to fall to one side. Oil thrown upon the surface

of water, soon spreads as a film over it, and defends it to a considerable degree from the contact and friction of the air.

Among the magnificent examples which have existed of artificial water-courses, were the aqueducts of ancient Rome, about twenty in number. Several of them exceeded forty miles in length, passing through hills in their way, and resting on tiers of splendid arches across the valleys. These were copied in other parts of the empire. In modern times the advancing art of engineering can furnish still more abundant supplies and at smaller cost. The Croton Aqueduct of New York, forty miles in length, which carries almost a river of pure water into that great and increasing city, to supply all its wants, and the aqueduct which has lately converted the beautiful Loch Katrine lying among the Grampian Hills, 370 feet above the sea-level, into the exhaustless supply-reservoir for the vast city of Glasgow with its 500,000 inhabitants—are notable examples.

While the aqueducts are cited as specimens of grandeur, we may mention the jetting fountains in the gardens of Italy and France as specimens of beauty. Those at Versailles have long been known to fame. Now those of the grounds of the Crystal Palace near London are worthy rivals.

"*Waves.*"

The form, magnitude, and velocity of waves, apparently without law, are yet subjects susceptible of complete mathematical analysis, as shown in an admirable article by the Astronomer Royal, Mr. Airy, in the 'Encyclopædia Metropolitana.' Here they must be treated with great brevity.

689. A stone thrown into a smooth pond, causes a succession of circular waves to spread from the spot where it falls as a common centre. They become of less elevation as they expand, and each new one is less raised than the preceding, until gradually the liquid mirror becomes again perfect as before. Several stones falling at the same time in different places, cause crossing circles, which, however, do not influence the progress of one another, otherwise than by increasing the heights and hollows at the points of their meeting,—a phenomenon seen in beautiful miniature at each leap of the little insects which cover the surface of pools in the calm hours of summer.—The rationale of the formation of these waves is as follows. When the stone falls into the water, because the liquid is nearly incompressible, a part of it is displaced laterally, and becomes

an elevation or circular wave around the stone. This wave then spreads outwards in obedience to the laws of fluidity, already explained, and the circle is seen to widen. In the mean time, where the stone descended, a hollow is left for a moment in the water, but owing to the surrounding pressure, is soon filled up, chiefly by a sudden upheaving from below. The rising water does not stop, however, when it has reached the general level of that around, but like a pendulum sweeping past the centre of its arc, it rises almost as far above the level as the depression was deep below it. This central elevation now acts as the stone did originally, and causes a second wave, which pursues the first; and when the centre subsides, like the pendulum still, it sinks again almost as much below the level as it had mounted above that: hence it has to rise again, again to fall, and so on for many times, sending forth a new wave at each alternation. Owing to the friction among the particles of the water, each new wave is less raised than the preceding, and at last the appearance dies away.

A wave passing through any gap or opening, spreads from it as a new centre; and a wave coming against a perpendicular surface of wall or rock, is completely reflected from this, and acquires the appearance of coming from a point as far beyond the reflecting surface, as its real origin or centre is distant on the side where it is moving.

690. So absolutely level is a liquid surface, and so sensitive or mobile, that the effect of any disturbing cause is perceived at great distances. A boat rowed across a still lake, ruffles its surface to a great extent; and although the widening waves become at last such gentle risings and depressions as not to be perceptible to the eye, they still produce a rippling noise where they terminate among the pebbles on the shore. In seas liable to sudden but partial hurricanes, the noise of breakers on the shore may tell of a storm which does not otherwise announce itself. The author once, in the Eastern ocean had an opportunity of studying waves of extraordinary magnitude rolling along when no wind blew, and therefore with unbroken surface, like billows of molten lead. At that very time, about a hundred and fifty miles to the north-east, a fleet of noble ships from India were contending with a hurricane—in which four of them foundered with all on board.

691. The common cause of waves is the friction of the wind upon the surface of the water. Little ridges or elevations first

appear, which by continuance of the force, gradually become loftier and broader, until they are the rolling mountains seen where the winds sweep over a great extent of water. The heaving of the Bay of Biscay, or, still more remarkably, of the open ocean beyond the southern capes of America and Africa, exhibits one extreme, and the stillness of the tropical seas, which are sheltered by near encircling lands, exhibits the other. In the wide archipelago of the east, where Borneo, and Java, and Sumatra lie, and the Molucca Islands and the Philippines, the sea is often fanned only by the land and sea breezes, and has been compared to a smooth bed, in which these islands seem to repose in bliss—islands in which the spice and perfume gardens of the world are embowered, and where the bird of paradise has its home, and the golden pheasant, and many other birds of brilliant plumage, among thickets so luxuriant, and scenery so picturesque, that European strangers find there the fairy land of their youthful dreams.—To one who has visited these islands in his early days, this description recalls vividly the simple truth.

692. In rounding the Cape of Good Hope, waves are met with, or rather a swell, so broad, that a few ridges and a few depressions occupy the extent of a mile. But these are not so dangerous to ships as what is termed a *shorter* or more abrupt sea, with steeper waves. The slope in the former is comparatively gentle, and the rising and falling, although greater, are much less felt; while among the latter, the sudden tossing of the vessel may be destructive. When a great ship is sailing directly before the wind, over the *long swell* described, of which swell the speed is much greater than that of the ship, she advances as if by leaps; for as each wave passes, she is first descending headlong on its front, acquiring a velocity so wild that she can scarcely be steered; and soon after, when the crest has passed under her, she appears climbing on its back, and her motion is slackened almost to rest, before the following wave arrives. To a spectator placed at such a time near the extremity of the bowsprit, and looking back on the enormous body of the ship, with crowded decks, nearly a hundred feet behind him, heaved by these billows as a cork is on a ruffled lake, the scene is truly sublime. When a coming wave lifts the stern and in the same degree depresses the bow, he is low in the hollow or valley between the waves, and sees only the ship rushing headlong down towards him as if to be engulphed: but

soon after, when the stern is down, and the bow is raised, he looks from his high station in the air upon an awful scene beneath him and around.

The velocity of waves has relation to their magnitude. The large waves just spoken of, proceed at the rate of from thirty to forty miles an hour.—It is a vulgar belief that the water itself of waves advances in the direction, if not with the speed of the wave, but in fact the *form* only advances, while the *substance,* except a little spray above, remains rising and falling in the same place, with the regularity of a pendulum. A wave of water, in this respect, is closely imitated by the wave running along a stretched rope when one end is shaken; or by the mimic waves of our theatres, which may be undulations of long pieces of carpet, moved by attendants. But when a wave reaches a shallow bank or beach, the water becomes really progressive, for then, as it cannot sink directly downwards, it falls over and forwards, seeking the level.

693. So awful is the spectacle of a storm at sea, that it generally disturbs the judgment; and, lofty as waves really are, imagination pictures them loftier still. Now few if any waves rise at their crest more than fifteen feet above the ordinary sea-level, which, with the fifteen feet that the surface afterwards descends forming the trough of the wave, give thirty feet for the whole height, from the bottom of any water-valley to an adjoining summit. This is easily verified by a person who tries at what height on a ship's rigging the horizon remains always in sight over the top of the near waves—allowance being made for accidental inclinations of the vessel, and for her sinking in the water to considerably below her water line, at the time when she reaches the bottom of the hollow between the two waves. The spray of the sea, driven along by the violence of the wind, is of course much higher than the summit of the liquid wave; and a wave coming against an obstacle, may dash to an elevation much greater still. At the Eddystone lighthouse, which is about ninety feet high, placed on a solitary rock ten miles from the land, when a surge breaks which has been growing under a storm from far across the Atlantic, it often dashes above the lantern at the summit.

The magnitude of waves is well judged of when they are seen breaking on an extended shore or beach. In the deep sea the wave is only a moderate elevation of the water, sloping on either side; but as it rolls towards the shore, its front becomes more

and more perpendicular, until at last it curls over and falls with its whole weight, and when several miles of it break at the same instant, its force and noise seem to shake the country around.

694. Along the east or Coromandel coast of India, during certain seasons, vast waves are constantly breaking, and forming what is called the surf; and as there are no good harbours there, communication between the sea and land is rendered impossible to ordinary boats. Some natives of the coast, at Madras, for instance, have hence become almost amphibious. They reach ships beyond the breakers by the help of what are called *catamarans,* consisting of three small logs of wood tied together. On these they secure themselves, and boldly advance up to the coming wall of water, which they shoot into, and rise to the smooth surface beyond it, like water-fowls after diving. Boats unsuited to the breakers often perish in them. The writer had gone on shore with a party on the coast of Sumatra, and during the hours spent there, a swell had arisen in the sea, which on their return was already bursting along the beach and across the river's mouth in lofty breakers. The boat in which he happened to be, regained the high sea in safety, but a larger boat, loaded with butts of water, which followed at a short distance was overwhelmed, and an officer and part of the crew perished.

695. There is a phenomenon observed at the mouths of many great rivers, called the *Bore,* which has resemblance to a wave. When the flood-tide returning from the sea meets the outward current of the river, and both have the force which in certain situations belongs to them, the stronger mass from the ocean assumes the form of an almost perpendicular wall, moving inland with resistless sweep. This is called the bore. It is, in fact, the great sea-wave of the tide, produced twice a day by the attraction of the moon, rolling in upon the land and inlets, where channels gradually narrowing concentrate its mass. In the different branches of the Ganges the bore is seen in a remarkable degree. Its roaring is heard long before it arrives. Smaller boats and skiffs cannot live where it comes, and are therefore drawn up on the shore; and as it passes the city of Calcutta, even large ships at anchor there are thrown into commotion. The nature and effects of this strong flood-tide are strikingly illustrated upon certain coasts where extensive tracts of sand are left uncovered at low water. In such situations, of which there are several on the western shores of Britain, as

Morecambe bay and the Solway firth, the returning tide is seen advancing with such rapidity, that the speed of a galloping horse can scarcely save a person who has incautiously approached too near. Many have been the victims of temerity or ignorance on these treacherous plains.

696. In the end of the year 1831, on the low flat coast of the Indian peninsula, north of Madras, one great wave of the kind now described was produced during a very high spring-tide of midnight, increased by an extraordinary wind, and spread ten miles inwards on the inhabited land. It had retired with the ebb-tide before morning, but the next day's sun disclosed a scene of devastation rarely equalled. Amidst the wreck of the villages and fields, there lay the drowned carcases of some thousands of human beings, mixed with those of elephants, horses, bullocks, wild tigers, and the other inhabitants of the land.

"*Fluids resisting the motion of bodies immersed in them, or themselves moving forcibly against other bodies.*" (See the Analysis, page 288.)

The same force is required to give, or to take away, or to bend motion in a fluid, as in an equal quantity of solid matter. A pound of water enclosed in a bladder is not more easily thrown to a given height than a pound of ice, or of lead; nor, if falling into the scale of a weighing beam, does it require less as a counterpoise; nor if made to revolve at the end of a sling, does it render the cord less tight.

697. A convenient measure of the force of moving water on an obstacle, or of the resistance of still water to a moving solid, exists in the facts already explained (Art. 678), that the pressure of a known height of fluid column produces from an orifice a certain velocity of jet, while conversely, that jet, or any current of equal speed, directed against the orifice, supports the column. The impulse given or received, therefore, by a flat surface in water, such as the float-board of a water-wheel, whether of a steam-boat pressing against the water, or that of a corn-mill pressed by it, is measured by the weight of the column alluded to, of which the height is according to the velocity and the breadth or diameter, according to the breadth or extent of the solid surface concerned. This estimate supposes that the pressure of or upon the surface is direct; if it be oblique, there is a diminution according to the rule given under the head of "resolution of forces."

698. Many persons, looking hurriedly at the subject of fluid resistance, would expect that if a body, as a boat, moving through water at a given rate meets a given resistance, and costs a given expenditure of force, it should just meet double resistance, and cost double force when moving twice as fast. But the resistance and force are more than four times greater with a double rate.

699. These facts are but other examples of a principle already explained in Art. 678, and when examined, are easily understood. A boat which moves one mile per hour, displaces or throws aside a certain quantity of water, and with a certain velocity;—if it move twice as fast, it of course displaces twice as many particles in the same time, and requires to be moved by twice the force on that account; but it also displaces every particle with a double velocity, for twice as many have to be pushed aside in the same time, and it requires another doubling of the power on this account: the power then being doubled on each of two accounts, becomes a power of four. In the same manner with a speed of three, three times as many particles are moved, and each particle with three times the velocity; therefore, to overcome the resistance, a force of nine is wanted; for a speed of four, a power of sixteen; for a speed of five, a power of twenty-five; and so forth: the relation being that which mathematicians indicate by saying *that the resistance increases as the square of the speed.** The corresponding numbers, up to a speed of ten, are as here shown:

Speed	1	2	3	4	5	6	7	8	9	10
Corresponding resistance .	1	4	9	16	25	36	49	64	81	100

Thus, even if the resistance at the bow of a vessel were all that had to be considered, the force of one hundred horses would only drag the vessel ten times as fast as the force of one horse. But there is another important element in the calculation, which farther increases the disparity between the motion produced and the force expended, *viz.*, the lessening, as the vessel's speed quickens, of the usual water-pressure on the stern,—which pressure, while the vessel is at rest, is just equal to the pressure on the bow; and the force therefore required to produce an increased velocity is still considerably greater than as noted in the table.

* See the Appendix, "Popular Mathematics."

There are few more important truths in physics than the law of fluid resistance to moving bodies, here treated of; it explains so many phenomena of nature, and becomes a guide in many matters of art. We proceed to set forth some interesting examples.

700. It explains at what a heavy expense of fuel and machinery high velocities are obtained in steam-boats. If an engine of about 50-horse power would drive a boat 7 miles an hour, two engines of more than 50, or one of more than 100, would be required to drive it 10 miles, and three such to drive it 12 miles; even supposing the increased resistance at the bow, as already stated, to be the measure of the whole work to be done, which it is not, and that engines worked to the same advantage with a high velocity as with a low, which they do not. For the same reasons, if all the coal which a ship could conveniently carry were just sufficient to drive her 1,000 miles, at the rate of 12 miles per hour, it would drive her more than 3,000 at a rate of 7 miles per hour; and more than 6,000 at a rate of 5 miles per hour. This is a very important consideration, for persons concerned in steam navigation to distant parts.

701. The same law shows the error of putting very large sails on a ship; the trifling advantage in point of speed by no means compensating for the additional expense of making and working the sails, and the risk of accidents in bad weather. The ships of the prudent Chinese have not, for the same tonnage, one-third so much sail as those of Europeans, and yet they move with sufficient speed for many purposes. A European ship under jury-masts, or make-shifts after a storm, does not lose nearly so much of her usual speed as people would expect.

702. This law explains also why a ship glides through the water one or two miles an hour when there is very little wind, although with a strong breeze she would only sail at the rate of six or eight miles. Less than the 100th part of that force of wind which drives her ten miles an hour, will drive her one mile per hour, and less than the 400th part will drive her half a mile. Thus also, during a calm, a few men pulling in a boat can move a large ship at a sensible rate.

703. These considerations show strikingly of what importance to navigation it might be to have, as a part of a ship's ordinary equipment, one or two water-wheels (or ready means of forming them), to be affixed upon the ship's side when required, like the

paddle-wheels of a steam-boat, and by turning which the crew might easily deliver themselves from the tedium, or even disastrous consequences of a long calm at sea.—This idea occurred to the author while in a ship completely becalmed for a considerable time on the Line: during which wearisome period, the breezes were often seen roughening the water a mile or two farther on; and any means that could have enabled the ship's company to advance her that little distance might have saved the delay. The wheels might be driven by connexion with the capstan, at which, under such circumstances, the crew would most willingly work. Delay in a large vessel often costs hundreds of pounds per day, and might retard the execution of important projects.—But the propelling of the ship in a calm seems by no means the most important purpose which such wheels might serve. If from disease, fatigue, or other cause, the crew were rendered inadequate to some existing necessities, two wheels affixed to the extremities of an axis crossing the ship might be equivalent in many cases to additional hands, or to a steam-engine of considerable power; for when acted upon by the water as the ship sailed, they would turn with the force of water-wheels on shore, and might be made to move the pumps, to hoist the sails, and to do any work which a steam-engine could perform. Many a gallant vessel has perished because the exhausted crew could no longer labour at the pumps, where such water-wheels as now contemplated, would have performed the work required for a much longer time.*

The law that resistance to a body moving in a fluid increases in a greater proportion than the speed of the body, applies where the fluid is aëriform, as well as where it is liquid.

704. A bullet shot through the air with a double velocity, for the reasons assigned above, experiences four times as much resistance in front, as with a single velocity; the motion being retarded also by the loss or diminution of the usual atmospheric pressure of 15 lbs. per inch on the posterior surface. It is true, farther, that when the velocities of bodies moving in air are very great, the resistance in front increases in a still quicker ratio than in liquids, and possibly because the compressibility of air allows it to be much condensed or heaped up before the

* The suggestion here made was acted upon a year after the publication of the first edition of the book.

quick moving body. Referenee is made to this subject in a future page.

705. The rule of reciprocal aetion between a solid and fluid, now explained, holds equally when the fluid is in motion against the solid, as when the solid moves through the fluid.

If a ship be anchored in a tide's way, where the current is four miles an hour, the strain on her cable is not one-fourth part so great as if the current were eight miles.

A wind moving three miles an hour is scarcely felt; if moving six miles, it is a pleasant breeze; if twenty or thirty miles, it is a brisk gale; if sixty, it is a storm; and beyond eighty, it is a frightful hurricane, tearing up trees by the roots, and generally destructive.

Supposing the wind to move one hundred miles per hour, there are one hundred times as many particles of matter striking any body exposed to it, as when it moves only one mile per hour, and each particle strikes moreover with one hundred times the velocity or force, so that the whole increase of force is a hundred times a hundred, or ten thousand. This explains how the soft invisible air may by motion acquire force sufficient to unroof houses, to level oaks, the roots of which have been spreading wide and gathering strength for centuries, and in some forms of hurricane, absolutely to brush every projecting thing from the surface of the earth.

706. The law of rapidly increasing resistance assigns a limit to many velocities, both natural and artificial.

It limits the velocities of bodies falling through the air. By the law of gravity, a body would fall with a constantly accelerating speed, but as the resistance of the air increases still more quickly than the speed, at a certain point, this resistance and the gravity balance each other, and the motion beeomes uniform.

707. The *parachute,* by means of which a person may safely descend to the earth from a balloon at any elevation, furnishes a good example. This contrivance, when opened out, resembles a large flat umbrella. The aëronaut is attached underneath it, and when it is let loose from the balloon, and opened, the resistance of its broad expanse limits the speed of its falling through

the air to about eleven feet in a second, or that which a man acquires in jumping from a chair two feet high.

No ship under canvas or with steam power, sails faster than about twenty miles in an hour.—And it is because the chief resistance to be overcome by steam-carriages on railways, *viz.* their friction, does not increase with their velocity like the water resistance to ships, that the speed of the former may so much exceed that of the latter.

No fish swims with a velocity much exceeding twenty miles an hour; not the dolphin, when shooting ahead of our swiftest frigates, nor the salmon, when darting forward with speed which lifts it over a waterfall.

And the flight of birds through the thin air has a limited celerity. The crow, when flying homewards against the storm does not face the wind in the open sky, but skims along near the surface of the earth in the deep valleys, or wherever the swiftness of the wind is retarded by terrestrial obstructions. The great albatross of the South Sea, stemming upon the wing the current of a gale so as to remain in company with a driving ship where the air is passing at the rate of eighty miles an hour, often takes short shelter on the lee-side of a lofty billow. The bird called the *stormy petrel* abides chiefly in the midst of the Atlantic Ocean, but the violence of the wind can sweep it from the waves, and cause its appearance on the solid shores. Vessels from the high sea, approaching a coast from which strong wind blows, often become resting-places to exhausted land birds, driven off the shore by wind which they have not strength of wing to stem;—sad evidences of the myriads which are constantly perishing where no resting-place is found, and where no human eye notes their fate.

The action or resistance between a meeting fluid and solid, is influenced much by the shape of the solid.

708. This follows from the explanations already given on direct and oblique impulse, in Arts. 161, 329. Experiment finds that a globe of wood floating in water can be drawn along at a certain rate by about half the force required to draw a block of the same diameter with flat surface and square corners. As a plough opens and penetrates the ground with ease proportioned to the sharpness of its wedge-like form, so does the wedge-formed ship plough easily through the water. If the prow of a ship were broad and flat like the end of a square packing case, it

would evidently, when forced through water, have to drive before it as fast as itself a large quantity of the water raised partly into the form of a wave, and resisting its progress, and would, moreover, be constantly urging that water to the right and left, out of its way at great cost of power. On the other hand, a prow of wedge form drives no water directly forward, but cuts or opens its way through, very gradually and gently at little cost of power. In the case of the plough the furrow left behind remains open, and the form of the hind part of the plough is immaterial; but in the case of the ship, the water has to close in behind, and by its pressure, to counterbalance in a degree the resistance of the water in front. If the stern part of a ship, therefore, be abrupt like the end of a packing case, the water can fall in but slowly to fill up the furrow called the ship's wake, and hence would arise an important cause of retardation. To favour, therefore, the motion of a ship through the water, the wedge-shape or tapering is required behind as well as before.

709. The following are instances of projecting or wedge-shaped surfaces, fitted to diminish the resistance to motion of solids in fluids. Fishes are wedge-like both before and behind, their form being modified, however, in relation to other purposes of equal importance to them as mere speed of motion. Of birds the same is true, and in flying they are observed to stretch out their necks, so as to make their form perfect for dividing the air. In the form of the under part of boats and ships, men have, in a close degree, imitated the shape of fishes. The light wherries which shoot about upon the surface of the Thames, appear to realize whatever imagination can picture of form combining utility with lightness and grace. There are boats used in China called *snake-boats*, seen on festive occasions, which are only about two feet broad, but perhaps a hundred feet in length, and when moved, as they are, by a multitude of rowers, their swiftness is extreme. The problem which has for its object, to assign for a ship's hull or bottom, the best possible form to give speed of sailing, with capacity for cargo, is not yet satisfactorily solved; so that a kind of empiricism prevails in the matter, and unexpected results often arise. The subject well merits attention, for when vessels have to chase and to flee, speed becomes of the first importance; and at all times the sailor's heart swells with delight to find his well-beloved vessel performing well.

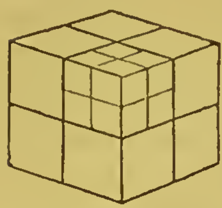
710. The following instances exhibit the mutual influence of meeting solids and fluids, where the surface of the solid is plane

or slightly concave.—In a water-wheel, whether the water is moving against the wheel, as where a stream acts to drive machinery, or the wheel is moving against the still water, as in the case of the paddle-wheels of a steam-boat, the extended flat faces of the vanes or float-boards give or receive an impulse proportioned to the area. When a wheel with float-boards has its lower part merely dipping into a stream of water, to be driven by the momentum of the water, it is called an *under-shot wheel;* when the water reaches the wheel near the middle of its height, and turns it by falling on the float-boards of one side as they sweep downwards in a curved trough fitting them, the weight of the water also is called into play. This modification is called a *breast-wheel;* and when the float-boards are shut in by flat sides so as to become the bottoms of a circle of cavities or buckets surrounding the wheel, into which the water is allowed to fall at the top of the wheel, and to act almost by its weight only, the modification is called the *overshot wheel.* To have a maximum of effect from wheels moved by the momentum of water, they are generally made to turn with a velocity about one-third as great as that of the water: and wheels moved by the simple weight of water usually have their circumference turning with a velocity of about three feet per second. The subject of water-wheels is one of the most important in practical mechanics; for moving water performs a great deal of labour for man. Where fuel is costly the water-wheel may be a cheap substitute for the steam-engine.

711. Oars for boats are made flat, and often a little concave, that the mutual action between them and water may be as great as possible. The webbed feet of water-fowls are oars: in advancing, they collapse like a shutting umbrella, but open outwards in the thrust backwards, so as to offer a broad concave surface to the water. The sails of ships, when they are receiving a fair wind, are seen to bulge or swell a little, and are supposed thereby to receive a stronger impulse.

712. The resistance between a meeting solid and fluid being nearly proportioned to the breadth and surface of the solid, it follows that large bodies, because containing much more matter in proportion to their breadth and surface than smaller bodies of similar form, are less resisted, in proportion to their weights, than smaller bodies.

The science of measures tells us* that a bullet or other regular solid of two inches diameter, has eight times as much matter in it as a similar solid of one inch diameter, while it has only four times the surface. This fact is well illustrated by putting eight dice or little cubes together, as here represented. They form one larger cube, of which, compared with a single die, the edge is evidently *twice* as long, the surface *four* times as great, and the quantity of matter *eight* times as great. Similarly, *twenty-seven* dice put together form a cube with sides *three* times as long, and the surface *nine* times as great as in a single die,—and so onwards. The solids are said to be to each other as the cubes of any of their corresponding lines. If a bullet of eight pounds therefore, and a bullet of one pound be shot off with equal velocity, because the larger has only half as much surface in proportion to its weight, and therefore to its motal inertia or force, as the other, it will go much farther than the other.



713. This important fact explains why large spherical shot, smaller cannon-balls, musket-bullets, pistol and swan-shot, and the common small-shot of the sportsman, all of which are generally discharged from their respective pieces with the same commencing velocity, have a shorter range always, as they are smaller in size. Even water is sometimes thrown from a gun or powerful syringe to stun birds, that they may be obtained with uninjured plumage; but as it soon divides in the air very minutely it reaches to only a short distance.

714. Water, falling through the air from a great height, goes on suffering a gradual division into smaller and smaller portions, which at last may be said to be nearly all surface; and these are then seen sinking slowly as a mist. The toy called the *water-hammer* is merely a small quantity of water enclosed in a tube which is exhausted or empty of air: when, by turning the tube, the water is made to fall from one end to the other, as there is no air to impede or divide it in its descent, it falls as one mass, and makes a sharp noise like the blow of a hammer.

715. The same law explains—why a spider's thread, like that of the gossamer, or a single filament of silk floats so long in the air before it falls, because of the greater surface in proportion to the quantity of solid matter;—why there is almost constantly

* See the Appendix.

suspended in the air, wherever active man resides, that immense quantity of very minute solid particles, which, when rendered visible by the sun's light passing directly through among them, are called motes in the sunbeam; particles which are constantly settling on household furniture, and rendering necessary the daily operation of dusting or cleaning;—why the fine dust sent aloft during the eruption of volcanoes is often carried by the wind to a distance of hundreds of miles;—why in the deserts of Africa the strong winds often transport fine sand from place to place, overwhelming caravans, and forming new mountains, which succeeding blasts are again to lift;—why in the bottom of a river, or in a tides-way, fine mud is found only where the current is slow; sand where it is quicker; pebbles, or large stones, where it is quicker still; while in rapids and waterfalls, only massy rocks can resist the fluid force. Now rock, pebble, sand, and mud, may all be the very same material, only in portions of different magnitude.

716. This law explains the operation of *levigating*, by which heavy substances insoluble in water are obtained in the state of a very fine powder. Any such substance is first ground or powdered in the ordinary way, and then diffused in a vessel of water. The grosser parts first fall to the bottom; and if the water be then passed into another vessel, the deposit in that will be of smaller portions; in a third vessel, with longer time allowed for subsidence, the deposit will be of smaller particles still, and so on, if desired. The fine powder of flint used in the manufacture of porcelain is obtained by levigation; as is also that of calamine stone, and other powders used in medicine and in various arts.

717. This principle explains why embankments formed of earth or clay, to restrain water, are so rapidly destroyed if the water be allowed to accumulate and run over the top. The particles of the earth or clay on the top, while dry, press on one another with all their weight, and form a tolerably resisting barrier; but if the water reach them, they half float, and are so easily carried along by the powerful friction of the passing water, that a small channel or gap is quickly rendered the outlet of a resistless torrent. In countries where the rivers, like the Po in Lombardy, are in many places retained in their channels at higher level than the surrounding fields by embankments of earth, a miscreant, by cutting a small gap in the embankment, might flood the whole of the low country. Some

cases of lamentable destruction have occurred in the fen-districts of England, by failure of embankments or sluices.

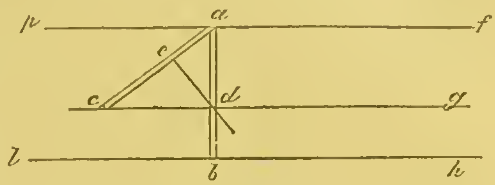
718. This law further explains how, by means of air or water, substances of different specific gravities, although mixed ever so intimately, may be easily separated. If pieces of cork and lead mixed be let fall together through the air, the lead will reach the ground first, and may be swept away before the cork arrives; —in a vacuum the whole would reach the ground at the same time, as is proved by the common experiment of the guinea and feather falling at the same rate in the exhausted receiver of an air-pump. Again, when a mixture of corn and chaff, as it comes from any threshing-machine, is showered down from a sieve in a current of air, the chaff being longer in falling, is carried farther by the wind, while the heavier corn falls almost perpendicularly. The farmer, therefore, by *winnowing* in either a natural or artificial current of air, readily separates the grain from the chaff; and, if he desire it, may even divide the grain itself into portions of different quality. Similar to the operation of separating chaff from corn by wind, is that of separating sand or mud from gold-dust by water:—the soil containing gold-dust is first spread on a flat surface, over which a current of water is then made to pass; which current carries away the lighter rubbish, and leaves the gold. If a mass of metal with a string attached to it be whirled about the hand for a time as a sling, and then let go, it flies off at a tangent with the string as its tail. And if a piece of metal be affixed on the end of a rod of wood, the rod then, whether simply falling through the air, or thrown from the hand, or advancing as an arrow, will follow the heavier metal as its point. The cork of a shuttlecock is always quickly in front, because it is less resisted in the air than the feathers.

The instances enumerated under this head serve to show how many and varied the results may be which flow from a single principle.

> When a fluid and a solid meet each other, obliquely, the impulse or effect is still perpendicular to the surface of the solid, as if they met directly, but is less forcible as the obliquity of the approach is greater. (See Art. 161.)

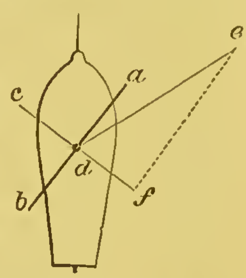
719. Suppose the double line *a b* to represent the edge of a smooth board, or any flat surface placed in a current of fluid

running with a certain speed and force in the direction of the lines with arrow points, *f p* and *h l*; the pressure on the board will be direct or at right angles to the board, and proportioned to the area of the surface. If then the



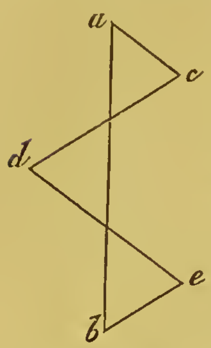
board be placed obliquely to the current, in the position *a c*, evidently the breadth of the current acting on the board will be as much less than previously, as the line *a d* is shorter than the line *a b* (Scientifically stated, the line *a d* is called the sine of the angle of obliquity—*See the Appendix.*) Then farther, the part of the current striking the board, and reduced to the breadth *a d*, strikes it not directly but obliquely, and therefore only with force represented by the line *a e* instead of *a d*. (See Art. 161.) That line *e a* is again the sine of the angle of obliquity, with the line *a d* for radius.

720. From this it appears that the wind blowing upon the sail of a ship, however obliquely, as from *e* to *d*, always presses it directly forward or perpendicularly to its surface, as from *f* to *d*, but acts less forcibly as the obliquity is greater. If the wind be represented, as to direction and strength, by the line *e d* approaching the sail *a b*, it will act on the sail as if it came from *f*, but with the smaller force *f d*, instead of the whole force *e d*. The effect, therefore, is the same as if the sail were pulled by a rope *d c*. We see in this, how a ship can be made to sail in a certain degree against the



wind:—for all the sails being adjusted so as to receive the wind in the direction here shown, a little behind their back-surface, they all act to produce the same result as if pushes were made in the direction *f d*, or if ropes were pulling from each in the direction *d c*, or parallel to it; and a force like *f d*, or a rope like *d c*, urging sideways as well as forwards—as instanced in the tow-rope of a canal boat at which the horse pulls—makes the vessel advance rapidly forward, but scarcely at all sideways, because the form of vessels causes them to pass forward at least twenty times more easily in the direction of their sharp bow, than sideways across their long broad side or keel; and therefore a force urging equally sideways and forwards, causes a ship to advance twenty miles in the direction of her keel, that is for-

wards, for one mile which she deviates sideways.—The deviation sideways, which in sailing-vessels must take place to a certain extent whenever the wind is at all oblique, is called the *lee-way*,



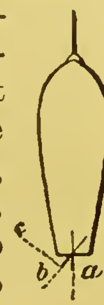
721. A vessel having to sail from *b* to *a*, while the wind blows directly against her course, or from *a* to *b*, is obliged to sail *close to the wind*, as represented in last paragraph, first, it may be supposed, to *e*, as represented by this figure, with the left or larboard side to the wind, then to *tack*, as it is called, or turn round, at *e*, and to sail to *d*, with the right or starboard side to the wind; then to go on the larboard tack again to *c*, and from thence to the port at *a*. A ship tacking as here represented makes an approach of one mile towards her port for nearly three which she sails through the water.

722. In making way against a *contrary wind*, the sails of a ship have to be pointed so nearly edgeways to the wind, that unless very flat, a portion of their surface becomes useless. The Chinese manner of rigging has, in this respect at least, some advantages, for in it bamboo reeds attached across the sails, render these as flat as boards. Thus when a Chinese ship has her yards and sails pointed edgeways to a spectator, he only sees the masts which support them.

The reason why a ship with several masts may sail faster when the wind is more or less from a side, than when directly astern, is, that in the former case the sails on all the masts are acting, although individually not to the best advantage, while, in the latter, the sails in front are becalmed by those behind them. A ship with a side wind may move a little faster than the wind itself, as is often true of the outer extremities of a windmill's vanes. A corresponding relation of a slow motion producing a quicker is observed when a slippery wedge is forced out two or three inches laterally from its place, by a weight which descends only one inch perpendicularly.

723. The law now under consideration explains the action of the *rudder* of ships,—that contrivance by which a single steersman can direct the course of a huge vessel before a stormy wind more steadily and safely than an adroit charioteer can guide his tiny phaeton on a common road. The helm or rudder is a flat projection from the stern-post of the ship, turning on strong hinges, in the manner of a door or gate, and moved by a beam or lever called the *tiller*, which proceeds from it forward

to where the steersman acts. In small vessels the tiller is above the deck, and the steersman applies his hand directly to it; but in large ships it is below, and is moved by ropes leading to the axle of *the wheel* on the deck, where the steersman stands with the compass before him. While the rudder points directly astern, as shown by the line *a*, which seems a continuation of the keel and stern-post, it does not affect the vessel's course; but if it be inclined ever so little to one side, as is the line *b* on the left or *larboard* side, the water immediately acts on it in the direction *c b*, perpendicular to its surface, and pushes the stern to the right or *starboard* side—an action equivalent to pulling the bow to the left or larboard.



724. It is possible to make a ship or boat steer itself, by placing a powerful vane on the mast-head, and connecting that with the tiller-ropes by two projecting arms from its axis. If it were desired to make the ship sail directly before the wind, the tiller-ropes would be connected with the arms of the vane so that the helm should be in the middle position, when the vane were pointing directly forward: should the vessel then from any cause deviate from her course, the vane by its changed position with respect to her keel, would produce a corresponding change on the position of the helm, just such as to bring her back to her course. Again, it is evident that, by adjusting such a vane and rudder to each other in different ways, any other desired course might be obtained, and which would alter only with the wind. The vane, to have the necessary power, would require to be of large size—a wide hoop, for instance, with canvas stretched upon it; and the rudder, to turn with little force, might be hung on an axis passed nearly through its middle, instead of, as usual, by hinges at one edge. Cases have occurred where shipwrecked persons might have sent intelligence of their disaster to a distant coast, by a small vessel, or even a log of wood fitted up in this way. The method admits also of other applications, as during war.

725. As fluids act on surfaces, in a direction perpendicular to them, the water on the right side of a ship's bow is always pressing it towards the left side; but owing to the equivalent and contrary pressure on the left side, the ship holds her course evenly between the two, or straight-forwards. When a ship, however, owing to a side wind, lies over or *heels*, as it is called, that side of the bow which sinks most is more pressed than the

other; and were there not then made a counteracting inclination of the rudder, constituting what is called *weather-helm*, the ship's head would come round to the wind. Now ships so rarely have the wind exactly astern and the masts quite erect, that to diminish the almost constant necessity for *weather-helm*, the mast or masts, and consequently the mass of the sails, are placed nearer to the bow than to the stern.

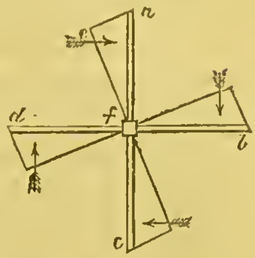
726. Again, because the bow of a ship is oblique below as well as on the sides, the water, when she moves, is constantly tending to lift the bow; hence when a vessel is dragged by a low horizontal rope, as a boat is when attached to a sailing ship's stern, or is moved by paddle-wheels, like steam-boats, the bow rises more or less out of the water, and the stern sinks in the hollow or furrow of the track; but when a ship is driven by sails, which are high on the mast, and are acting therefore as by a long lever to depress the bow, the two opposing tendencies just balance each other, and the vessel sails evenly along.

727. The form of the fore part of a ship has great influence, as explained before, on her speed of sailing, but the form of the hind part, called the *run*, from the middle to the stern, is also very important. When a ship is at rest, there is of course as much forward pressure of water about the stern as of backward pressure about the bow; but when she sails, she is running away from the propelling pressure, and is increasing the resisting pressure. A gradual tapering of the hind part, therefore, or a *fine run*, as it is called, which allows the water to apply itself readily to it, as it passes along, is essential for quick sailing.

728. It may be observed here that while greater breadth of prow causes increased resistance to the advancing motion of a ship, greater length of hull has very little influence, for the wedge of the prow opens the way for any length of hull, and there can arise only a little increase of friction from increase of length. The same principle explains why in artillery practice elongated shells or shot can be thrown much farther than globular masses of the same weight.

729. The *common windmill* furnishes another very important illustration of the action or push of fluids on oblique surfaces. The face of the windmill, as a whole, is turned directly to the wind, but the faces of the four flat vanes or sails, which appear as the arms of the great wheel, are individually oblique. Thus

the edge *a* of the vane *a e*, is more forward as regards the coming wind or a spectator in front, than the edge *e*; and the action of the wind, therefore, being perpendicular to the oblique surface *a e*, pushes it in a degree towards *a*, as the point of the arrow shows. The same remark applies to each of the other vanes, where the edges *b*, *c*, and *d* are in front, and those marked by the fainter lines are farther back; so that each vane produces an equal effect in turning the wheel. The law of the "decomposition of forces" (Arts. 159 and 161) tells in what proportions the force of the wind is exerted to push the wheel backwards against its supports, and to turn it round.



Windmills were first used in Europe in the fourteenth century, and they are still of great importance in countries where there are no waterfalls, and but little fuel for steam-engines. In some of the richest European landscapes every height is crowned by its busy windmill, grinding corn, or sawing wood, or pressing oil-seeds; and over the plains, similar wheels are pumping water for domestic use, or incessantly draining the land.

730. The *smoke-jack* of our chimneys is a small windmill, driven by the ascending current of air in the chimney.

731. The *feathering of an arrow* acts in part on the principle of the windmill. The feathery projection from the shaft is not quite straight, but winds round it a little, like the thread of a screw; and the arrow, therefore, constantly turns as it flies, and goes straight to its object even if the shaft itself be somewhat bent, because any deviation is constantly correcting itself.

732. The rifle-barrel in fire-arms has spiral furrows or threads along its interior surface, so that the bullet in passing out receives a turning motion round the line of its flight, corresponding to that of a feathered arrow, and producing similar results. A bullet which receives any other turning motion than round the line of its course,—and most bullets from an unrifled barrel do acquire such, owing to some irregularity of their form, or to unequal friction at the mouth of the piece,—is sure to deviate from its course, because unequally pressed or resisted by the atmosphere. The greater friction and pressure from which it turns away is on that side of the ball which is advancing more quickly than the centre. A good rifle fixed to its place will send a succession of shots through the hole made in the target by the first shot.

Within a few years rifled cannon have been manufactured, and being of wrought iron instead of cast, according to the plans of Sir William Armstrong, they bear stronger charges of powder than were formerly used, and so send their shot to a much greater distance. The improvements in artillery referred to have already changed remarkably the character of military operations.

733. It was supposed by some that a wheel which the wind turned by *direct* action on flat projections round the circumference, as water turns common water-wheels, would be more effective than the windmill-wheel above described, which is turned by *oblique* pressure on its face, and accordingly a wheel like a water-wheel, only with broader vanes, was constructed and placed so that only one side was exposed to the wind,—but it was found to be a comparatively powerless machine. The wider expanse of the oblique-vaned face was found to be much more than compensation for the obliquity of the wind's action upon it.

734. A windmill-wheel made to turn during a calm by force applied to its axle, is, according to the law of action and reaction being equal and contrary, pressed endways with nearly the force used in turning it, owing to the reaction of the still air through which its oblique vanes are caused to sweep. If in such an experiment the windmill-wheel is supported on the mast of a floating boat it urges the boat along with the force referred to.

735. Such a wheel placed in a short cylindrical tube or passage has been used to produce an artificial wind or air-current for the ventilation of closed spaces.—A small wheel of the kind carried in the hand of a person walking along in a calm turns as if wind were blowing on it at the rate of the walker's motion, and if connected with a train of wheels and an index, like those of the common gas-meter, it indicates the length of space passed through.—Such a wheel placed in the wind tells the speed of the wind.—And such a wheel fixed on the end of a spindle and caused to spin round like a humming-top, rises into the air, constituting a kind of flying machine.

736. There are situations where it would be advantageous to use water-wheels constructed with arms and oblique surfaces like the common windmill-wheel: namely, in streams deep enough to allow the whole wheel to be immersed. Because water is more than 800 times heavier than air, bulk for bulk, its force either acting when itself in motion, or in resisting and re-acting against other motions is proportionally great. This explains the

marvellous efficacy of such a water-wheel when used on board ship, as now with the name of screw-propeller, constituting the great instrument of steam-navigation on the high seas.*

* The so-called screw-propeller when first offered to notice was far from being completely understood either by those who proposed it—several of whom had taken patents for it as a novelty—or by those opposed to it as being less effective than the paddle-wheel. The advocates for it first used a screw of several turns of the flange, whence its name was derived; but they soon found that two turns answered better than three or more, then that one turn was better than two; and, lastly, that half a turn, divided into two opposite arms, like two arms of a windmill, answered best of all. At first few on either side seemed to be fully aware of the following facts:—

1. That this propeller differed from the paddle-wheel almost exactly as the common broad-faced windmill with oblique surfaces differs from the wheel partially exposed to the wind, as described in Art. 733.

2. That the so-called mechanical power the screw, does not at all waste force on account of the obliquity of the surfaces of contact, provided the external screw or nut is firm or unyielding.

3. That a fluid surface if pressed upon by a solid which passes as rapidly along or over it as the propeller-surface passes over the water-surface against which it bears, resists nearly as effectually as a solid surface would, and that the propeller therefore, when the pitch of the flange is properly adjusted, loses less force by the yielding of the water than a paddle-wheel does.

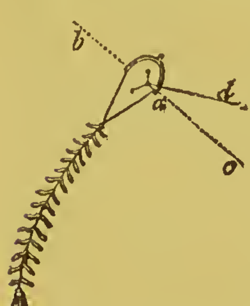
This very important and little-considered fact of the almost solid resistance of a fluid to a rapidly passing pressure is seen in such cases as the following. A cannon ball always rebounds from the surface of water when it is shot in a nearly horizontal direction. The ball when it descends and touches is resisted by the inertia and reaction, not by its own bulk of water, but of perhaps a hundred times as much within the one second or two of contact as it passes quickly along, and it thus rebounds and plashes several times before its motion is exhausted. The like happens when a boy at play throws a flat pebble along the surface of a pond and sees it skip and leap forward. The same principle is illustrated by the long resisted and slow descent of a broad leaf falling from a tree when it zig-zags and thereby touches much air,—in the slow slanting motion of the boomerang descending,—in the mode of flight of the great albatross, whose wings appear scarcely to move as he glides about in the atmosphere supported by the resistance offered to the under surface of his expanded wings by the new air, which he every instant reaches.

The author, when he published this work, before the screw-propeller had been tried at sea, explained the true theory by reference to the windmill-wheel, &c., as here repeated; but not having had occasion to consider the matter closely, he did not then question the opinions which had been given by eminent practical men, that there would be loss of power in substituting the oblique, lateral, or twisting pressure of the screw for the direct backward pressure of the paddle-wheel. After a time, however, learning by accident that a friend of his who knew little of science had been induced to lend a large sum of money to build a vessel of size sufficient to test completely the qualities of the screw, he was led to review the subject in detail, and he then saw the good reasons stated in this note for approving of the project. There was opposition and unfavourable judgments from many high quarters—as there had been before in regard to gas-lighting, locomotive engines on railways, steam navigation on the high seas, the electric telegraph, penny postage, &c.—but gradually the opposition ceased. The vessel referred to was afterwards well known as the *Archimedes*, so named by the last patentee of the screw—who erroneously thought that the propeller resembled in principle the screw of Archimedes, spoken of here in Art. 745. This experiment drew the attention

737. The effect of a single oar projecting from the stern, used to propel a boat or vessel, in the manner called *sculling*, is referable to the law of oblique impulse now under consideration. The oar or scull rests on a round-headed prop or nail at the stern, and is made to vibrate from side to side. In all its positions it has the surface which presses the water turned obliquely backwards; hence the re-action of the water drives the boat forward.—In China, vessels of more than 100 tons are moved by a single large sculling oar, which half the ship's company may be urging at the same time. A sculling oar may be regarded as a single vane of such a propelling wheel or water-screw as above described, made to sweep across, behind the vessel, alternately to the right and to the left.

738. The action of a fish's tail, and of the bending of an eel or snake in water, partly resembles that of the sculling oar. Many people believe that the tail of the fish is only the rudder of the body, and that the fins give it forward motion—as is true of a bird's tail and wings,—but the fish's tail is in fact the great instrument of motion, while the fins serve chiefly to steady and direct the motion. And there has been the very erroneous opinion that the oblique pressure of the fish's tail occasions necessarily a loss or waste of force.

739. A *paper kite* rising in the air is another example of oblique actions. Its cord *d* is attached to it above the middle of its loop, and therefore so as to make it present always an oblique surface to the wind; but by the action of the wind, being perpendicular to its surface, it rises as if pushed up in the direction *c a*, or as if drawn up in the direction *a b*. A kite might be made large enough to lift the weight of a man. A cat has been sent up at a kite's tail, and has come down safely under a parachute from a great elevation.



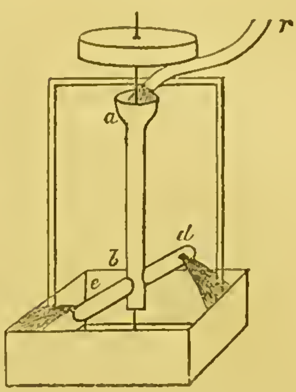
There are some other pieces of hydraulic apparatus of which the explanation is conveniently given here.

740. *Barker's Mill.*—It consists of an upright tube *a b*, with

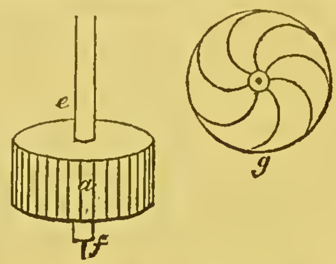
---

of Government, and of engineers generally, to the subject, and a new construction of ships of war and others in all countries has been the momentous result.

a funnel at the top, into which water pours from any reservoir. The water fills the tube *a b*, and its two arms *b c* and *b d*, in each of which, near the end, there is an opening, from which the water spouts, and by its re-action, or the unbalanced pressure on the interior of the tube opposite to the opening pushes the arm in the contrary direction. Then as the two holes are on opposite sides of the arms, both co-operate to turn the axis round, and thereby to turn a millstone above, or to do any other work.



741. The *Turbine* resembles the Barker's mill in principle, although differing in form. It has below, instead of the two arms with spouting apertures, a cylindrical drum, *e f*, close at top and bottom, divided into a number of curved channels as outlets for the descending water, all pointing in the same way, as shown in the sectional view *g*. The re-action of the water spouting out all round turns the cylinder. This arrangement allows columns of water of vast height to be used to produce the motion. The machine is extremely simple, requiring no valves nor internal parts but plates or walls of division. The rapidity of rotation becomes extreme from high waterfalls. Some are made having the power of 50 horses or more. They may be used to give motion to any kind of machinery.



742. These two forms of apparatus are moved by descending water. They can be converted into powerful machines for lifting water by employing the force of steam or other power to give them motion so as to produce centrifugal force in the water. 1st, If the Barker's mill, instead of receiving water from above, has its arms high up and its vertical tube rising from an ordinary well, and if it be first filled with water, and made to turn quickly, the centrifugal force of the water in the arms near the openings at *b* and *c*, will cause a gushing out there, while atmospheric pressure will raise more from the well to supply the discharge. 2nd, If the turbine be placed with its axis horizontal, and be whirled rapidly while water is admitted freely to its centre by its axis, the whole being immersed, it will operate with singular efficacy. This apparatus, constructed by Mr.

Appold and others for the International Exhibitions, has attracted much notice under the name of the *centrifugal pump.*

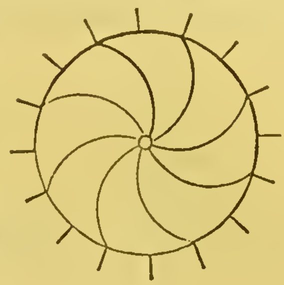
"*Fluids lifted in opposition to gravity.*" (See the Analysis.)

Water, as we have seen in former parts of this work, is to the living universe, in some degree, what the blood is to the animal body, and a constant supply and circulation are required. This supply is provided for to an admirable extent, by the operation of natural causes; but for many purposes of society more complete control is still required. A great variety of means have been devised for raising it, some of which, sufficient to illustrate the whole, are now to be mentioned.

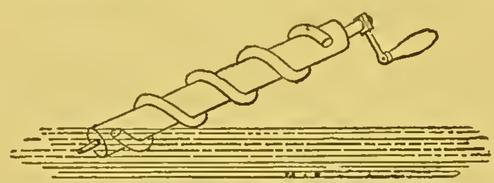
743. Water may be raised in a bucket attached to a rope to be pulled up by the hand.—A rope carrying a large bucket may be drawn up more easily by being wound on a barrel or axle turned by a winch.—There may be a succession of buckets on an endless rope, rising one after the other, and when emptied above, descending again on the opposite side of the wheel or axle which supports and lifts them, to be refilled. This combination is called the *bucket-machine.*—Instead of buckets on such an endless rope or chain, there may be a succession of flat pieces of wood, drawn up through a large tube or barrel, like loose-fitting pistons, and raising a copious stream: this is the contrivance called the *chain-pump.*—Or simply an endless rope of hair, very rough, passing round one wheel above and another below, may be moved quickly by turning the upper wheel, so that a mass of water adhering by friction and otherwise to its rising half, shall be thrown off by centrifugal force into a reservoir at the top where it passes over the upper wheel: several such ropes may be placed side by side to increase the effect.—But the most common and important of water-raising engines are the *lifting and forcing pumps*, already described at page 228. They are used to draw from wells, to drain mines, to send a supply over cities, to pump ships, to throw water for extinguishing fires, and for many other purposes. The so-called centrifugal pump described in Art. 742, is admirable for certain limited purposes.

744. A stream of water passing through a garden, or in the midst of fields, may have beauty with little utility, if it cannot be employed to irrigate the land around. In many fields and gardens of Persia where the heat of the sun is intense, the streams are

caused, by their own action, to lift a part of their water into elevated reservoirs, from which it again flows in sloping channels to wherever it is required. A large water-wheel may be placed so that the stream shall turn it, while buckets around its circumference are filled as they sweep along below, and are emptied into a reservoir as they pass above—or instead of buckets, the spokes of the wheel may themselves be made hollow, and curved as here represented, so that their extremities may dip into the water below and receive a quantity of it, to run along them as they rise, and be discharged into a reservoir at the centre. Such have been called *Persian wheels*.

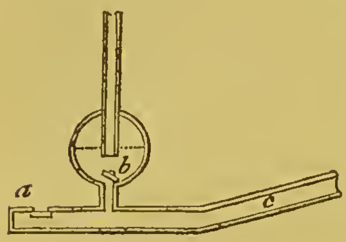


745. A pipe, open at both ends, wound like a screw upon a sloping barrel, and made to dip its lower mouth into water at each revolution of the barrel, will also raise water: the lower portions of the turning pipe are always charged with water, which rises in them to the top, as if drawn up on an inclined plane. Archimedes was the inventor of this beautiful water-screw, and his name has remained to it. It may be turned by hand, or by the action of the passing stream.



746. It had long been observed in household experience and elsewhere, that while water is running through a long pipe, if a cock at the extremity be suddenly shut, a smart shock and noise are produced there. The reason is, that the forward motion of the whole water filling the pipe being instantly arrested, and the momentum of a liquid being as great as of a solid, the water strikes the cock with as much force as if it were a spar of wood or bar of metal having the same weight and velocity as the water. Then, as a fluid presses equally in all directions, a leaden pipe of great length, may, near the extremity, be widened, or even burst in this experiment. This forward pressure of an arrested stream is conveniently used as a force for raising water, and the arrangement of parts contrived to render it available has been called, on account of the shock produced, the *water-ram*. The ram may be described as a sloping pipe in which a stream runs, having a valve at its lower end shut at intervals to arrest the stream, and having a small tube rising from near that end

towards a reservoir above, to receive a portion of the water forced up at each interruption. The water allowed to run for a time, in a pipe ten yards long, two inches wide, and sloping six feet, acquires momentum enough to drive, on the shutting of the cock, about half a pint, into the air-vessel of a tube leading to a reservoir forty feet high. The valve is so contrived that the stream works it.—In this figure, which represents the lower end of the water ram, *a* is the opening by which the stream ordinarily escapes from it, and the valve or flap seen below the opening is that which by suddenly shutting arrests the stream. The valve is made so heavy, that the stream must run for a certain time to acquire force enough to shut it: and in the instant of its shutting, a portion of the advancing water passes upwards through the other valve *b* towards the high reservoir. The water in the main pipe then becoming stagnant again, no longer has power, by its weight alone, to keep the valve *a* shut: this, therefore, falls open and the stream begins again, again to be arrested as before; and as long as the supply of water lasts, the action of the apparatus continues. The action of a water-ram has been compared to the beating of an animal's pulse. The upright tube has usually a reservoir at the bottom, which first receives the gush of water, constituting there an air-vessel *b* (described in Art. 527), which, by the air's elasticity, converts the interrupted gush first received, into a nearly uniform current towards the reservoir. The supply of air to this vessel is maintained by the contrivance called a *shifting-valve.*



In the preceding examination of the doctrines of fluidity, we have had to review many of the phenomena of nature and art most important to man; and we have seen how clearly intelligible most of them become when referred, by a methodical arrangement, to the few "fundamental truths" of Natural Philosophy. Simple and almost obvious as they now appear, however, every advance was a distinct step in the gradual progress of discovery and invention, and probably when first made filled some ingenious mind with intense and pure delight. (Art. 480.)

PART III.

(CONTINUED.)

SECTION IV.—ACOUSTICS; OR, PHENOMENA OF SOUND AND HEARING.

ANALYSIS OF THE SECTION.

1. SOUND *is heard when some sudden shock or impulse occurs in any body having communication through the air or otherwise with the ear.*
2. *If such impulses are repeated at very short intervals, the ear cannot attend to them separately, but hears them as a* CONTINUOUS SOUND. *This is* UNIFORM, *or what is called a* TONE, *if the impulses be similar and at equal intervals, and it is called* GRAVE *or* SHARP, *according as these are few or many in a given time. All continued sound is but a repetition of impulses.*
3. *When the number of impulses in a given time producing some uniform continued sound has a simple relation, as of double, triple, quadruple, half, third, fourth, &c., to the number producing some other such sound which is heard either simultaneously, or a little before or after, the ear in general is pleasingly affected by the circumstance; and the sounds are said to have* MUSICAL RELATION *to each other, or to be* ACCORDANT, *while others not so agreeing are termed* DISCORDANT.
4. *The impulse which causes the sensation of sound* SPREADS *or is propagated in all bodies, somewhat as a wave spreads in water, with decreasing strength as the distance increases, but with a velocity nearly uniform for each substance, and which in air is about* 1,115 *feet per second.*
5. *Sound is* REFLECTED *from smooth surfaces, and hence arise many curious and pleasing effects called* ECHOES, *&c.*
6. *The structure of the ear most interestingly illustrates and is illustrated by the laws of sound.*

---

747. EARLY inquirers into nature had remarked that in most instances of noise or sound there was present a shock or trembling

of the sounding body, often visible, but sometimes discoverable only by other means; it was visible, for instance, in the string of a harp, in the reed of a hautboy, in the prongs of a tuning-fork, in the lip of a bell: but it was reserved for the moderns to understand fully, that the animal organ called the ear, is merely a structure of parts delicately adapted to be affected by the concussions or tremblings of things around; and that sounds in all their varieties are merely such motions, affecting the ear through the medium of the air which surrounds it, or of some other body, or series of bodies, reaching from the trembling thing to the ear.

The delicacy and complexity of an organ destined to feel and to distinguish such slight and varying influences, and the vast importance of it to man, as that which makes him capable of using language, while it is his ever-watchful monitor of surrounding occurrences, and the channel by which the fascination of music enters, render this subject, to all who love to read in nature what so clearly reveals designs of the Divine author, a very pleasing study.

Because all the bodies around us are immersed, in common with ourselves, in the ocean of air which covers the earth, we are much more frequently warned of the shocks and tremblings of which we have been speaking, by their effect on the air, than in any other way; hence the early conclusion that air was necessary to sound, and hence, in part, the reason why the doctrines of sound have generally been accounted a part of pneumatics. We shall now find, however, that all bodies are more or less fitted to convey these tremblings, and that air in many cases is neither the quickest nor the best conductor. Although our notions on the subject are thus corrected, it is still convenient to study the theory of sound in connection with *Pneumatics*.

1. "*Sound is heard when any sudden shock or impulse occurs in a body having communication, through the air or otherwise, with the ear.*" (Read the Analysis.)

748. Common instances of a single impulse are—the blow of a hammer—the clap of hands—the crack of a whip—a pistol-shot—any explosion—the near thunder-clap.

The loudness of sound conveyed by air depends on the air's density. A bell enclosed in the receiver of an air-pump is heard less and less distinctly as the air is withdrawn, and in a

vacuum is not heard at all.—Even the blow of a hammer, in a vacuum, is not heard if care is taken to prevent the shock from being communicated through neighbouring bodies.—In the thin air about a lofty mountain-top the report of a pistol is much less loud, and human voices are weaker.—In the condensed atmosphere of a diving-bell a whisper is loud.—When the craters of volcanoes and various other resemblances to the constitution of our earth were first discovered in the moon, some persons are said to have watched during the stillness of night to hear the thunder there:—not reflecting that there is no sound-conveying medium between.

2. *Impulses very quickly repeated cannot be separately distinguished by the ear, and hence are felt as one continued sound, of which the pitch or tone depends on the number occurring in a given time. All continued sound is but a repetition of impulses.* (Read the Analysis.)

749. If a wheel with teeth be made to turn and to strike any elastic plate, as a piece of quill, with every tooth, it will, when moved slowly, allow every tooth to be seen and every blow to be separately heard; but with increasing velocity the eye will gradually lose sight of the individual teeth, and the ear, ceasing to perceive the separate blows, will hear only a smooth continued sound, called a *tone*, of which the character will change with the velocity of the wheel. An apparatus of this kind has been made with an indicator attached to tell the number of teeth passing in a given time to produce any particular note.

In like manner the vibrations of a long harp-string, while it is slack, are separately visible, and the pulses produced by it in the air are separately audible; but as it is gradually tightened, its vibrations quicken, so that at last, where it is moving, the eye sees only a shadowy line broader near the middle; and the distinct sounds which the ear lately perceived, seem to run together, and are felt as one uniform continued tone, which constitutes the note or sound then belonging to the string.

750. It is the elasticity of any string used to produce a tone, as in musical instruments, which causes the repetition of the percussions, and therefore the continuance of the sound. The string having been pulled by its middle to one side, and then let go; is, owing to its elasticity, carried back quickly to the straight or middle position of rest; but by the time that it has reached this, it has acquired a momentum which, like the momentum of

a vibrating pendulum, carries it nearly as far beyond the middle station, as the distance from whence it came:—it has to return therefore, by its elasticity, from this second deviation, in the same way; but still passing the middle as before, it has again to return; and thus continues passing and returning, or vibrating as uniformly as a pendulum does, until the resistance of the air and friction gradually bring it to rest. Then a large vibration of any string, like a large oscillation of a pendulum, occupies very nearly the same time as a smaller, because the farther that the string is displaced or bent, just so much more forcibly, and therefore more quickly, is it pulled back again by its elasticity, and hence the pitch and uniformity of the tone produced by a musical string is not affected by the different force with which the finger of the player may touch the string. According, however, as the vibrations of a string are more extensive in a given time, the impulses given to the air are more sharp or forcible, and the sound becomes louder. Vibrations which are comparatively few and slow, strike the ear very gently, as in the flapping of a pigeon's wing, or in the play of an elastic switch shaken in the hand.

751. The most simple and familiar instance of sounding vibration is that of an elastic cord extended between two fixed points, as in stringed instruments of music: but because elastic bodies generally, when by any force their natural form is for an instant altered, recover it when allowed, not by a first effort, but like the string or a pendulum, after a series of oscillations, almost all such bodies repeat many times an impulse once given to them, and thus may become the means of producing a continued sound.—If a solid rod of steel, glass, or any other elastic substance, be fixed firmly at one end and left free at the other, and if that other be then pulled a little to one side of its station of rest, and suddenly let go, it will immediately seek again that station, but by the momentum acquired in the approach, will go beyond it: it will then return as before, but again to pass, and so will continue to vibrate with diminishing force for a considerable time.—A schoolboy, thus, sticks the point of his penknife into the bench, and by one touch makes it produce a continued uniform sound of considerable duration.—The prongs of a tuning-fork, or of the common sugar-tongs, vibrate and sound in the same way.—In the musical snuff-boxes and chimney-clocks, the sounds are produced by the vibration of little rods of steel, differing in dimension, fixed by one end, in a row,

like the teeth of a comb, and touched by small pins or points projecting from a turning barrel.—Any elastic flap, as of metal or of tough wood, fixed over an opening, so as to stand away from it a little when not pressed by passing air, but to close the opening momentarily if so pressed, becomes a sounding reed when air is gently forced through the opening :—thus, the air first pressing on the flap to close it, causes a momentary interruption of the current, but the flap immediately recoiling from the blow, as well as by reason of its own elasticity, again opens the passage, and the continued rapid alternation of the shutting and opening produces the tone.—The reed of a clarionet is a thin plate of elastic wood, made to vibrate in this way.—The drone of the bagpipe and the common straw-pipe, are reeds of nearly the same kind.—The Chinese mouth-organ, and the sweet instruments not long ago introduced under the names of æolina, symphonion, and concertina, have reeds which differ from these only by beating *through* the opening instead of merely *on* its face.—Elastic rods simply resting on supports at both ends, or suspended by their middle, will also vibrate : a musical instrument is thus made of pieces of glass laid upon two strings, and struck by a cork hammer : in the island of Java, a rude instrument of the same kind is made of blocks of hard elastic wood.—A portion of a hollow sphere, or any cup-shaped vessel of elastic metal, very readily takes on a vibration, during which its form is constantly changing from the perfect round to the oval, and conversely ; there is consequently repeated percussion of the air, and a continued sound, and the thing is called a *bell.* A bell may be made of any elastic substance, as metal, glass, earthenware (buyers ring earthenware to ascertain its soundness), and even of hard wood.—The *Chinese gong* is a metallic vessel shaped like the lid of a large round band-box, having a manner of vibration very peculiar, and producing sounds that are rousing and sublime.—The *drum* has a tense elastic membrane on which the blows of the drum-stick are received : its tone ceases quickly because the motion of so broad a surface is much resisted by the air.—In the flute, flageolet, common organ-pipes, &c., the air is forced through narrow passages, and is divided by sharp edges, in such a way as to suffer repeated but perfectly regular condensations or interruptions sufficient to affect the ear ; and hence the endless variety of pleasing continued sounds which these instruments are known to produce.

752. For the production of a tone, it is of no consequence in

what way the pulses of the air are caused, provided they follow with sufficient rapidity and regularity. We may name, in addition to some of the instances given above, the pure sound produced by the motion of a fly's wing—long supposed to be the voice of the insect; but because it ceases instantly when the fly comes to rest, now known to depend altogether on the motion of the wings. Similar effects are produced by passing a finger-nail quickly across the ribbed surface of a piece of hair-cloth, or along the surface of a large harp-string covered with wire. The clacking of a corn-mill, and the noise of a stick pulled along a grating, are not tones, only because the pulses follow too slowly.

If an orifice, from which a stream of air is issuing, be shut and opened regularly at very short intervals by parts of a wheel, such as described in Art. 749, passing close to it, the rapid succession of slight impulses will produce a clear tone, of which the pitch will vary with the speed of rotation. This is the principle of the very ingenious instrument called the syren, used in experiments on sound.

Where a continued sound is produced by impulses which do not, like those of an elastic body, follow in regular succession, the effect ceases to be a clear uniform sound or tone, and is called a *noise.*—Such is the sound of a saw or grindstone—the roar of waves breaking on a rocky shore, or of a violent wind in a forest—the roar and crackling of houses or of a wood in flames —the mixed voices of a talking multitude—the diversified sounds of a great city, including the rattling of wheels, the clanking of hammers, the voices of street-criers, the noises of manufactories, &c.: which rough elements, however, at last mingle so completely that the combined result has been called "the hum of men," from analogy to the smooth mingling miniature sounds which constitute the hum of a bee-hive.

"*Grave and sharp sounds.*" (Read the Analysis.)

The difference of sounds, which depends on the different number of vibrations of the sounding body in a given time, lets them be divided into those called *bass*, *low*, or *grave* notes, for comparatively few and slow vibrations; and those called *high*, *shrill*, or *sharp*, for vibrations more numerous and quick.

753. The frequency of vibrations in strings, increases with their *shortness*, *lightness*, and *tension*—for if a string be *long* or *heavy*, there is a greater mass of matter to be moved than in one short or light, and thence a slower motion; and if a string be slack,

the force of elasticity which pulls it from any deviation back to the straight line, will be so much the less. The facts are, that a string taken of half the length, or of one-fourth the weight, or of quadruple the tension of another string, vibrates twice as fast on any one of these accounts, and like proportions hold for other differences.

These truths are familiarly illustrated in the violin. The low or bass string is thick and heavy from being covered with metallic wire, and the others gradually diminish in magnitude and weight, up to the smallest or treble. The strings are tuned to each other by being attached by one end, to moveable pins, which, when turned, increase or diminish their tension; and the sound produced by each is afterwards varied to a certain extent, by the performer pressing different parts of it with the finger against the board, so as to shorten or lengthen the vibrating portion.

An analagous law, as to the influence upon tone, of weight and dimensions, holds with respect to bells, glasses, reeds, &c., and enables us to use these also in the construction of musical instruments.

3. " *When the number of impulses producing some continued sound has a simple relation, as of half, third, fourth, &c. to the number producing some other sound which is heard either simultaneously, or a little before or after it, the ear is much and pleasingly affected; and the sounds are said to have musical relation to each other, or to be accordant, while all others are termed discordant.*" (Read the Analysis.)

754. Understanding now that all continued uniform sounds are produced by a repetition of similar beats or vibrations at equal intervals, we perceive that in the series from grave to sharp, there must be such as, with respect to the number of beats in a given time, are related to each other as the numbers 1, 2, 3, 4, &c.; and if any two of these sound together, there must be at every second, third, fourth, &c., beat of the one a coincident beat of the other. We should naturally expect the ear to be otherwise affected by such correspondence, than when the coincidence is either less frequent, or not regular. Accordingly we find that all sounds which have such simple relations to each other, are remarkably agreeable to the ear, either when heard together, or in close succession; while those in which the

coincident beats are farther apart, are heard with indifference, or are felt to be positively harsh and disagreeable.

It is a fact offering itself to be noticed here, that the coincident or double pulses of any two concordant sounds become the cause or elements of a third tone, very distinct from them, but which is always heard with them, and is called their *grave harmonic*, or *resultant:* it is the same as a simple sound having as many vibrations in a given time, as there are coinciding beats between the two other sounds.

755. If a long musical string be made to sound, and the number of its vibrations in a given time be ascertained, we find that if only half of it be allowed to vibrate at a time, as when a moveable bridge is placed under the middle, or a finger there presses it against a board, that half will vibrate twice as fast; and similarly, a third part will vibrate three times as fast; a fourth part, four times as fast; and so on, producing the sounds or tones thus nearly related to each other. A striking illustration of this is afforded by the string of a violoncello, when made to vibrate by a bow moved very gently across it, near the bridge. It often divides itself spontaneously into two, three, or four, &c., equal vibrating portions, with points of rest between them called nodal points. When this happens, there are heard in succession, or even together, not only the sound or note belonging to the whole length of the string, but also, more feebly, the subordinate notes belonging to its half, third, or fourth, &c., according to circumstances, beautifully mingling with the first sound, and forming with it a rich harmony. Often in such a case the subordinate sounds swell with such force as to overpower for a time the fundamental note. The same harmonic sounds may be produced still more certainly, while drawing the bow across the string, by touching the string lightly with the finger, at one of the points where we wish it to divide. Even a varied air may so be played, by the harmonies only.

756. The sounds thus belonging to a single cord or string, and produced by its spontaneous division into different numbers of equal parts, constitute, when heard together or in succession, what may be called a simple music of nature herself. It is produced pleasingly, as just described, by the single string of a violoncello; but also in a very interesting manner by the instrument called the Æolian harp.

757. The Æolian harp is a long box or case of light wood, with harp or violin strings extended on its face. These are

generally tuned in perfect *unison* with each other, or to *the same pitch*, as it is expressed, except one serving as a bass, which is thicker than the others, and vibrates only half as fast; but when the harp is suspended among trees, or is placed in any situation where the fluctuating breeze may reach it, near a window partially opened, for instance, each string, according to the manner in which it receives the blast, sounds either entire, or breaks into some of the simple divisions above described; the result of which is the production of that combination and succession of related sounds so generally pleasing. After a pause this fairy harp may be heard beginning with a low and solemn note, like the bass of distant music in the sky: the sound then swells as if coming near, and other tones break forth, mingling with the first, and with each other: in the combined and varying strain, sometimes one clear note predominates and sometimes another, as if single musicians alternately led the band: and the concert often seems to approach and again to recede, until with the unequal breeze it dies away, and all is hushed again. —It is no wonder that the ancients, who understood not the nature of air, nor consequently even of simple sound, should have deemed the music of the Æolian harp supernatural, and, in their warm imaginations, should have supposed it to be the strain of invisible beings from above, come down in the stillness of evening or night to commune with men in a heavenly language of soul intelligible to both. But, even now that we understand it well, there are few persons so insensible to what is delicate and beautiful in nature, as to listen to this wild music without emotion. To the informed mind it is additionally delightful, as affording admirable illustration of those laws of sound which human ingenuity has at last completely traced.

758. As the simple scale of sound, called a *chord*, which nature thus gives by the spontaneous dividing of a single string, has considerable vacancies in it, human taste or feeling, long before there was any theory of music, had joined to it the notes of two additional strings, one a third shorter, and therefore giving sounds sharper or more acute than it, and the other a third longer, and therefore giving tones more grave; of which additional notes, while part agreed, or were in unison with certain notes of the principal chord, the remainder just served to fill up its larger intervals, and to complete a scale of nearly uniform interval—as three ladders having unequal intervals between their steps, might still, if placed together, complete a

stair of easy ascent. The relation between these strings or chords is such, that the principal beats thrice for twice of the low chord, and the high chord beats thrice for twice of the principal:—and in the usual scale of notes, the principal is the fifth note above the lower and fifth note below the higher. So truly natural is the scale thus formed, that it has arisen in all nations, however remote or unconnected; and an untutored individual, in attempting to raise his voice by regular steps, falls into it very readily. The scale has eight steps or notes, including the extremes, from any tone and the tone above it vibrating twice as fast, or the tone below it vibrating half as fast; these two tones or notes being hence called the *octaves* above and below the *note* with which they are compared, and the intermediate notes which fill up either octave from the fundamental note are distinguished by the names of *second, third, fourth,* &c. in ascending or descending. The numbers which express the relations of beats among the notes of an octave are easily found, from our knowing the relative number of beats in the notes of any one simple chord, and the relation as above described of the three chords forming the compound scale. The following table exhibits on the first line these relations or the arithmetical expression for the beats of an octave; in the second line the corresponding lengths of a given string required to produce them; in the third line the English designation of the notes by letters, and in the fourth line the continental designation by names, these names being the first syllables of certain verses formerly sung by learners.

Relations of vibrations	1	$\frac{9}{6}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Length of string	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$
English characters	C	D	E	F	G	A	B	C
Continental names..	ut	re	mi	fa	sol	la	si	ut

The musical scale, however far extended, is a repetition of similar octaves, so that any note in it vibrates just twice as often as the corresponding note in the octave below, and half as often as that in the octave above. The lowest note which is perceptible to the common ear has about twenty beats in a second, and the highest, about thirty thousand; there being included between these two, a range of nearly ten octaves. To certain ears the extremes of this range are inaudible, as if their power did not reach so far. Some persons do not hear at all

the sharp note of the grasshopper, while some are equally insensible to the lowest tones of an organ or piano; and yet to all, the perception of intermediate sounds may be equally perfect. Few musical instruments comprehend more than seven octaves, and the human voice in general has only from one to three, the female voice being in pitch an octave higher than the male.

759. If the intervals in the musical scale were all equal, a performer might choose indifferently any note as a fundamental or key note, and would only have to attend to the number of intervals above and below it; but, in fact, the relation of the three constituent chords is such, that the third and seventh intervals in ascending from a key note are only about half as large as the others. It is owing to this circumstance that in *changing the key* on any instrument, certain notes belonging to other keys are about half a note too low or too high, that is, too *flat* or too *sharp*, and must be changed accordingly. And hence, when an instrument is to be used to play in all keys, its larger intervals must be divided into two parts at least. The fact of these unequal intervals, ill understood, is what gives an appearance of great complexity and difficulty to musical science.

760. *Melody*, in music, is when notes, having the simple numerical relations of beat which we have been describing, are played in succession: *harmony* is when two or more such notes are sounded together. The effect of both is delightfully increased by what is called *measure*, viz. making the duration of the notes or strain correspond with certain regular divisions of *time*. This gives to the listener an anticipation, to a certain degree, of what is coming, with the pleasure of having expectation realized, as happens similarly in regard to the metre and rhyme of poetry: it moreover enables the memory to retain musical combinations of sound. The airs of the Æolian harp, which observe no *time*, cannot be learned by rote or repeated. The music of a single drum is chiefly that of *time*.

761. *Melody*, *harmony*, *time*, and *varying intensity of sound*, are the four constituents of music, and it seems that almost every state of mind has, in some combination of these, an appropriate expression, intelligible to the general feeling of the human race. The exact relation between the movements of the animal spirits, as it has been expressed, or the fluctuating stream of feeling, and the varying flow of sound in a musical composition, is not clearly understood, but the fact of their correspond-

ence and its consequences are very remarkable. Under many circumstances, the association between the feeling and the expression is so strong, that the latter is often spontaneously betraying itself;—witness the almost constant humming, or low song, of some contented beings when alone, and usefully employed—the singing and whistling of happy children, or of the light-hearted rustic living among the beauties of nature—the heart-rousing strain of the hunter or warrior—and the tender expression of many of the modifications of anxiety and sorrow. The musical sensibilities are by no means limited to the human race, for while no emotional expression seems to men more exquisitely beautiful than that of the nightingale during the evenings of spring and summer, or of the thrush and blackbird through the days of sunshine, there cannot be a doubt that these untutored songsters themselves are giving utterance to a kind of delight of which their own nature is susceptible.

The *accompaniment* of an air afforded to a singer by one or more instruments, and which is so pleasing, is chiefly the sounding simultaneously, in a subdued manner, some other notes of the chords to which the several vocal notes belong. *Duets* and more complicated *concert-pieces* have their origin from the same source: and highly cultivated musical sense can even follow and enjoy several melodies played together.

Musical notes, by whatever instrument produced, have to each other the same numerical relations in the beats or vibrations which constitute them. The different qualities of tone, therefore, from different instruments, can only depend on peculiarities of the single beats, as to whether they are sharp or soft, strong or weak, and accompanied or not by their natural harmonics. Such is the extraordinary nicety of perception which the human ear possesses in this respect, that it can not only distinguish different kinds of instruments, as a flute and clarionet, playing the same note, but with respect to the human voice, goes to the extent of recognizing almost each one of many voices singing the same air. One of the greatest charms of concert-music is that a particular voice and the different instruments may take up separately, parts of the strain suited to their individual expression: the flute and hautboy, for instance, breathe softness; the trumpet and drum arouse; the harp rolls forth its brilliant chords; the violin leads the clear sound through rapid and endless variety; and so of the rest.

762. That there might be correspondence in instruments when

played together, and a known pitch when played apart, it became necessary to fix on some tone or certain number of vibrations as a point of comparison. Hence *tuning-forks* have been made of steel, with length of prongs calculated to produce a certain note. This note is usually the fourth A or *la*, from the bass of the pianoforte, and vibrates about 440 times in the second;—and when the note of the same name on any instrument is *tuned* in unison with this, the other notes can be easily adjusted according to the harmonic relations above explained.

Almost every substance or contrivance that can produce an uniform continued sound may enter into the composition of a musical instrument: hence the almost endless variety which the world has seen. The chief classes of instruments are *stringed instruments, wind instruments*, and *bells* or *rods*.

763. Of the *stringed instruments*, we may mention the *harp*, the *lyre* or *lute*, the *guitar*, the *viol* of all sizes, and the *pianoforte*. The harp, lyre, and lute were the inventions of antiquity, and have brought down with them from remote times a thousand delightful associations. They quickened the inspiration of the bards and poets of the younger world, and they were the beloved companions of many noble spirits of succeeding times. Their great charm appears to have been in their power to heighten the emotions produced by music's twin sister, poetry; and the combined effects seem to have been magical. The other instruments mentioned are of comparatively modern invention, particularly the pianoforte; and their perfection has assisted in carrying the combinations of musical sound to degrees of complexity of which antiquity dreamt not. It is a question, however, whether the style of much of the music now in vogue do not prove rather a degeneracy, than a desirable refinement of musical taste. Music is a language of nature, intelligible at once, in a degree, to all susceptible minds; but modern art is attempting to make of it an artificial and conventional language, in which there may be fashion and change. The ornaments and accompaniments are made often so overwhelming, that the *melody*, in which the idea and sentiment really reside, is masked and almost lost; and an unpractised ear, particularly if listening to an *organ*, often discovers only an almost unmeaning succession of chords. And when a singer, abandoning the natural simplicity of melody, strains to execute with the voice the complicated movements which belong properly to instrumental accompaniments, the attempt often destroys the poetry, by either rendering

the words inaudible, or by sacrificing their natural expression to some supposed appropriate expression of the ornamental music. These considerations may account in part for the insensibility of many highly endowed persons to *what is now called* excellent music. Some of the tricks on the voice and on instruments, at present common, are, to natural or graceful music, nearly what tumbling and rope-dancing are to natural and graceful gesture. And when we hear noted professors manifest unwillingness to sing a simple expressive ballad, or to play an unadorned melody, must we not conclude that the natural sense of music has left them, as the relish for simple but the most invigorating fare has left the morbid epicure?

764. The *guitar*, as affording an accompaniment to vocal music, has many advantages. It is not too loud, yet the strains are very distinct: it admits of most touching expression; command of it is easily learned to the extent desirable as an accompaniment, by any one who should attempt to perform music at all; it is portable and cheap. The great facility of accompaniment on it depends on this, that the player is able by one position of the hand to touch the strings in such way that the sounds of all the six shall belong to the same chord:—three positions of the hand, therefore, for one key, produce all the notes and chords which a simple accompaniment requires; and the hand soon falls into these so readily, that the player is hardly sensible of exerting volition in regard to them.

Among *wind instruments* are, the *flute*, the *flageolet*, the *organ*, the *clarionet*, the *hautboy*, the *horn*, the *trumpet*, &c. The pitch or tone of a tubular wind instrument, just as of a musical string, has relation to its length; and the vibrations causing the sound are waves or undulations of air passing from the mouth to the extremity of the tube; being more frequent, therefore, as the tube is shorter:—when the bottom of the tube is closed, the wave has to come back again, and thus renders the note twice as deep or grave. It appears, also, that on blowing more strongly, the air in the tube divides into equal vibrating portions, as a string may divide to produce its harmonic sounds, and produces thus all the harmonic sounds belonging to the fundamental note of the tube. By blowing into a common German flute, for instance, it is possible to produce five ascending harmonics without moving the fingers at all. The music of a trumpet is limited to these four or five notes of the same chord; but in the flute, and other instruments with holes, the

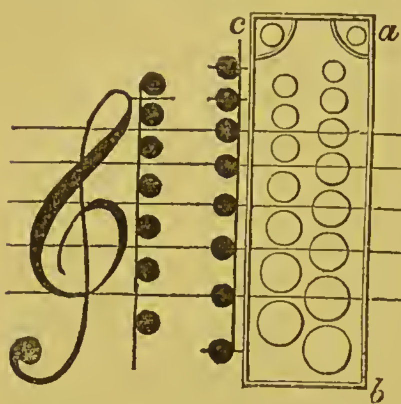
effective length of the tube is calculated from the upper end to the nearest hole left open ; and each length has its harmonics.

If a tuning-fork, Jew's-harp, or any such sounding body, be held at the open end of a tube or other empty space, of dimensions calculated to produce a frequency of undulation in its contained air according with the pulses of the sounding body, then the tube or space will immediately give out its own beautiful tone : and if the space be enlarged or diminished in a double, triple, or any other simple proportion,—as a tube may be, by a piston moved up or down in it, then will its notes become the fifth, octave, twelfth, &c., above or below the original tone, although that tone continues unchanged. The tones of the Jew's-harp are well known to depend in a degree on the varying dimensions of the player's mouth ; but to obtain perfect music from it, three harps at least, to be substituted one for the other during the performance, are required to produce the notes of the three constituent chords of the common musical scale.—In wind-instruments with reeds, the tone depends on the stiffness, weight, length, &c., of the vibrating plate or tongue of the reed, as well as on the dimensions of the tube or space with which it may be connected.—The sounds of the human voice are the sweetest of all, and are produced by the vibrations of two delicate membranes situated at the top of the windpipe, called the *glottis,* with a slit or opening left between them, for the passage of the air. The tones of the voice are grave or acute, according to the varying tension of these membranes, and to the size of the opening.—In the *organ* there is a pipe for each note, and wind is admitted from the bellows to the pipes, by the action of keys, like the keys of a pianoforte. The organ may be played also very perfectly by a barrel, made to turn slowly under the keys, and to lift them in passing, by pins projecting from it at the required situations.

Bells are often conjoined in sets, having the usual musical relations, and to some persons their music is very agreeable. There is in the tolling of a single bell a loudness and solemnity rendering it a fit accompaniment of funeral rites.—The *Chinese gong* partakes of the nature both of the bell and of a great drum, and has something in its sound which singularly arouses.

765. *Bells* or *goblets* of glass sound still more perfectly than those of metal, and when, by gentle friction on their edges with the wetted finger, their tones are called forth, nothing can exceed them in softness and purity. These may be continued for any length of time, and may be made to swell and diminish

like the human voice or the notes of the Æolian harp. A set of glasses, therefore, attuned to each other, according to the harmonic scale, becomes, for certain kinds of music, a very perfect instrument. It is, in fact, an Æolian harp at command. Dr. Franklin, who first constructed a set, simply doubled the long line of glasses upon itself, making two rows, and placed the half-notes on the outside. The writer, during some experiments on sound, found the *zig-zag* arrangement here represented to possess advantages. The small open circles represent the mouths of the glasses standing in a box *a b c*, and the relation of the glasses to the musical notes, as commonly written, is shown by the five music lines and spaces which here connect them. The learner discovers immediately that one row of the glasses produces the notes written *upon* the lines, and the other row the notes written *between* the lines; and so mentally commands the instrument after a simple inspection. This arrangement also renders the performance easy, for the notes most commonly sounded in succession are contiguous; and the usual relations of the notes forming a tune are so obvious to the eye, that much of the theory of musical combination and accompaniment is easily explained. The set of glasses here represented has two octaves, and with the additional *flat seventh* and *fifteenth*, seen at *a* and *c*, which, when required, may be substituted for the corresponding glasses in the rows, it is capable of playing the greater part of the simple melodies. Other half-notes, if desired, might be placed in outside rows. The player stands at the side of the box between *a* and *b*, and has the notes ascending towards the right hand, as in a pianoforte.



Musical ear.

766. Philosophers have not yet been able to account for a remarkable difference among individuals, in regard to their perception of the musical relations of sounds. Many persons, without understanding anything of acoustics, or having studied music as a science, can tell instantly whether various notes, heard together or in succession, have to one another the relations called musical—and which we now know to depend on

their comparative numbers of beats in a given time ; and they quickly recognize and learn to repeat tunes, and even to sing a fit second or bass to the performance of another. There are other persons, again, with an equally perfect sense of hearing, who can neither tell if an air be played in tune, nor what air it is, nor can they learn to sing alone, or to accompany. The former class of persons are said to have a *musical ear*, and the latter to want it; and although cultivation may raise mediocrity to considerable expertness, it cannot bestow the faculty where naturally wanting. On this subject there is a very common misconception, which becomes a source of mortification on one side, and of arrogance on the other, *viz.* that the possession of a musical ear, or the power of distinguishing notes, is the indication of all the finer qualities of the mind, and that the want of it proves an opposite deficiency. The opinion which Shakspere makes Lorenzo give of "him who hath not music in himself," is often triumphantly cited as applicable to all who want the distinguishing ear. The truth, however, is, that many who possess this musical characteristic in a remarkable degree, are deficient in almost all else that humanity reveres,—witness the weak minds and disorderly lives of so many professed musicians, —while many, again, who have it not, are otherwise examples of excellence, and exquisitely sensible to the other beauties and harmonies of nature. In fine, many distinguished poets and philosophers have had no musical ear. That much of the charm of music is often due to early associations, as well as to peculiar aptitude in the individuals, is proved by the effects well known of the Swiss airs, when heard by native Swiss in foreign lands; and, indeed, of the national melodies of all countries, where people are happy, and mix song with their usual occupations,—it not being in nature, that at any period of life, or in any clime, persons should cease to deem those strains lovely, which recall vividly the delights of infancy and childhood; modulations learned in general from a parent's voice, probably an excellent mother's, whose affection was so long around them as their shield and their guide.

767. The prejudice of which we have spoken in the last paragraph and in Art. 763, with respect to musical ear and musical taste, are the causes which, in the present day, condemn many young ladies, possessed of every species of excellence and talent except that of *note-distinguishing*, to waste years of precious time in an attempt to acquire a talent, aptitude for which

nature has not granted, and when they have succeeded as far as they can, they have only the merit of being machines, upon which tunes are set as upon a barrel-organ, and of which the performance is often far from being pleasing to good judges. Such persons, when liberty comes to them with age or marriage, generally abandon the offensive occupation; but tyrant fashion will force their daughters to run the same course. The waste of time now spoken of, is but one of many evil consequences which arise from the prevailing erroneous notions with respect to music.

"*The tremors or undulations which cause the sensation of sound spread in all bodies, solid or fluid.*" (Read the Analysis.)

768. As air consists of material particles held far apart from each other by strong mutual repulsion among them, we can conceive how an impulse and forward motion given to a certain portion of the particles is transmitted to those beyond, by the increase of repulsion as they approximate; and from the second layer in the same manner to a third, and so on. And as in fluids the particles all mutually rest against, or repel each other, we can conceive why a motion produced in any part of a mass should be felt in every direction. The explosion of gunpowder, in which there is a sudden production of a large quantity of aëriform matter, gives a shock all round which spreads as a spherical wave to a great distance.

769. Although material particles in the form of liquid or solid are so much nearer to each other than in the form of air, we still have many proofs, as stated in Art. 76, that they are not in absolute contact, and we therefore see the reason why the impulses producing sound should be transmitted through a liquid or solid in the same manner as through air, and even, by reason of the greater proximity of the particles, should spread more quickly and forcibly than in air.

770. Instances of sound carried by air were given at page 322: as further examples, we may cite the cases of what are called *sympathetic sounds.* Most elastic solids, when of certain shapes, being sonorous, that is to say, being fitted to tremble when struck, with a certain frequency of oscillation, depending on their weight and shape, &c., if the air around them be made to tremble by any cause, with the velocity which they are fitted to take on or produce, they immediately begin to

tremble in unison with the air; and their motion or sound may continue after the original cause of it has ceased. Thus almost any clear tone produced near a pianoforte whose dampers are raised, finds a responsive string, and if bits of paper are strewed upon the strings generally, those falling on the strings which return can vibrate in unison or as octaves to the sounding body are soon shaken off, while the others remain. A harp or guitar in a room with loud-talking company, is often mingling a note with their conversation. A wine-glass or goblet may be caused to tremble (and if, on a table at all inclined, even to fall), by a person sounding on a violoncello near it, the note accordant to its own.

Sounding bodies vibrate much more quickly, or have sharper tones, if placed in light hydrogen, than in common air; and more quickly in common air, than in any of the heavier gases: because the lighter the surrounding fluid, the less is the resistance to a body moving in it. Thus also a bell will ring under water, but with a much graver sound than in the air.

771. That water is a vehicle of sound, is proved, by the fact last mentioned,—by the distinctness with which the blows of workers around a diving-bell are heard above,—by the fact that fishes hear very acutely, &c.

772. The following are instances of sound conveyed by solids. —A scratch of a pin at one end of a wooden log is distinctly heard by a person applying his ear at the other end, although through the air it may not be audible, even to the person who makes it.—Savages often discover the proximity of enemies, or of prey, by applying an ear to the ground and hearing the tread.—The approach of horsemen at night is easily discovered anywhere in the same way.—The report of a cannon placed on ice is carried much farther and faster by the ice, than by the air around.—In the military operation of mining, or cutting a way under ground for the purpose of entering a citadel or blowing up fortifications, the approach of the enemy is often discovered by the subterranean sound of the pioneer's tools.—The awful muttering of earthquakes is merely the sound of subterranean explosions, conveyed from amazing distances, by the solid earth.

A superstitious man, sleeping in the upper story of the end house of a row, had for some time heard, during the dead of the night, a singular beating noise near the head of his bed. There was no adjoining house beyond the wall, nor was there

anything going on in his own house to account for it, and he at last deemed it supernatural. Accident eventually discovered that in a hovel built in the garden at the bottom, and outside of the wall against which his bed stood, there was a wooden clock hanging, of which the sound, while all else was still, became audible aloft.

It is easy to ascertain whether a kettle boils, by putting one end of a stick or poker on the lid, and the other end to the ear; the bubbling of the water then appears as loud as the rattling of a carriage in the street, although another person sitting near does not hear it at all.—A slight blow given to a steel poker or a steel triangle, of which an end is held to the ear, produces a sound which is even painfully strong.

773. The readiness with which solids receive and transmit sound is further perceived in the fact, that a small musical box, while held in the hand, is scarcely audible, but when pressed against a table, or a door, will rival a little harp. The vibration communicated from the box pervades the whole of the wood, and the extended surface of that acting on the air increases the effect. The construction of violins, harps, guitars, &c., and of sounding-boards generally, is governed by the same law. In the dancing-master's *kit* or small fiddle, which he carries in his pocket, there may be the same strings and the same bow as for a violin, but it has very little sound, because the extent of its surface is so small. A piece of metal called a *sourdine,* when fixed upon the bridge of a violin, damps the sound, because it is a dead mass resisting the motion of the elastic wood.

774. The fact of solids conveying sound so much more perfectly than air, has been applied to useful purposes in medicine. Dr. Laennec, of Paris, proposed some time ago to listen to what was going on in the interior of the body, and of the chest particularly, by applying one end of a wooden cylinder, which he called a *stethoscope* or *chest inspector*, to the surface, and resting the ear against the other end. The results of this happy thought have been valuable in enabling medical practitioners to discover with certainty important conditions of inward parts and functions, with respect to which, without the stethoscope, there could be only vague conjecture.

The actions going on in the chest are, the entrance and exit of the air in respiration, the voice, and the motion of the blood in the heart and blood-vessels;—and so perfectly do all these declare themselves to a person listening through the *stethoscope*,

that an ear once familiar with the natural and healthy sounds, can instantly detect deviations from them. Hence this instrument becomes a means of ascertaining certain diseases in the chest, or freedom from them, almost as effectually as if there were convenient windows for visual inspection.—When it is considered that a considerable proportion of the inhabitants of Europe die of diseases of the chest, such as inflammations, abscesses, consumptions, dropsical collections, aneurisms, and various affections of the heart and blood-vessels, each of which requires an appropriate treatment, the importance of such a means may be judged of. By many medical men this instrument was at first ridiculed as a piece of quackery, as it really is in the hands of an ignorant man pretending to judge by it; but the adoption of successful modes of treatment has often been suggested by discoveries made by it; and often are the distressing apprehensions of patients and their families completely relieved by the assurance obtained through it that there is no danger. Some of the opposition once offered was attributable to the defect which had existed in medical education, of leaving many students without that knowledge of general physics, or natural philosophy, or the laws of nature, which would enable them to appreciate at once and to use aright any mechanical means calculated to be useful in their art.

"*Velocity of sound.*" (See the Analysis.)

The velocity of light is such, that for any distance on earth its passage may be regarded as instantaneous. The velocity of sound is very much less.—If a woodman be observed at his occupation on the hill, his axe is seen to fall a considerable time before the sound of his blow reaches the spectator's ear.—The flash of a gun fired at a distance is seen long before the report is heard.

775. Most accurate experiments have been made to ascertain the velocity with which sound travels in the atmosphere; and it is found to be about 1,120 feet per second, or a mile in about four seconds and a half; varying a little with the density and temperature of the air.

By noting then how long the flash of a gun is seen before the report reaches the ear, one may learn the distance of the ship or battery from which the gun is fired. The captain of a chasing ship might thus discover, by shots fired from the object of his pursuit, its distance. In the same manner the distance of thunder

may be ascertained: and one reason of the long continued roll of thunder is, that although the lightning darts instantly through a whole chain of clouds, even of miles in length, the sounds produced at each break in the chain are only heard in succession, as they arrive at the ear. The pulse at the wrist of a healthy man is a convenient measure of time for ascertaining distances by the motion of sound,—each beat marking nearly a second, and therefore indicating a distance of nearly a quarter of a mile.

A line of muskets fired at the same instant cannot appear a single report to any person who is not in the centre of a circle, of which the line forms a part.

An extended orchestra of musicians cannot be heard equally well from all situations near them: hence the absurdity of a monster band where good music is intended.

Wind affects the velocity of sound just as a current in water affects the motion of a sailing ship.

Sound in the open air decreases in intensity from the centre where it originates, according to the same law as gravitation or light; that is to say, at double distance it is only one-fourth part as strong; at triple, a ninth, and so on.

776. By confining the undulation of sound, however, in tubes, which prevent its spreading, its force diminishes much less rapidly, and it will therefore extend to much greater distances.—In many manufactories, and even private dwellings now, there are pipes for the conveyance of sound leading to all parts; so that verbal communications may be made through them to great distances.

Sound travels in water about four times quicker, and in solids from ten to twenty times quicker, than in air. The blow of a hammer given to a wall by a person at one end, may be heard twice by a person at the other, *viz.* almost immediately by an ear applied to the wall, and a little after through the air. The like is often observed by persons who converse through lengths of iron tube laid under the surface of the earth.

"*Reflection of sound.*" (Read the Analysis.)

777. As a wave of water turns back at a smooth wall or other such obstacle, so that at any distance from that, after the reflection, it appears just what it would have been at the same distance beyond, had there been no obstacle, only moving in a different direction; so the pulses or waves of sound are regularly

reflected from flat surfaces, and produce what is called an *Echo.* Such flat surfaces of nature's works are found only among the rocks and hills; and hence arose the beautiful fiction of the ancient poets, that Echo was a nymph who dwelt concealed among the rocks. Science has now disclosed the secret of the viewless Echo; but who does not vividly recollect the wonder and delight with which he has listened, in the morning of his days, to his own shrill call returned to him from some bold precipice, perhaps across a river?

The quickness with which an echo is returned to the place where the sound originates, depends of course upon the distance of the reflecting surface; and, as sound travels 1,120 feet in a second, a rock at half that distance returns a sound exactly in one second. The number of syllables that can be pronounced in a second, may, in such a case, be repeated distinctly, but the end of a longer phrase would mix with the commencement of the echo. The breadth of a river can thus be ascertained where there is an echoing rock on the farther shore. A perpendicular mountain's side, or lofty cliffs, such as in many parts skirt the British coasts, return a loud echo of artillery, or of thunder, to a distance of miles.

If two bold faces of rock or wall be parallel to each other, a sound produced between them is repeated often, playing like a shuttlecock from one to the other, but becoming more faint each time until heard no more. In some situations, particularly when the sound travels thus above the smooth surface of water, a pistol-shot may be counted forty times.

The remarkable resonance of narrow inclosed spaces depends on this continued reverberation. In wider spaces it may modify the effect of music by converting a simple melody, which is a *succession* of notes, into a harmonized piece, where companion notes are heard; and a young flute-player may be first charmed with his own music when he finds himself performing a duet with Echo. But resonance injures the distinctness of speech, so as even in some ill-contrived halls of assembly, or theatres, to render the articulation unintelligible. Small rooms or near surfaces give no perceptible separate echoes, because the interval of time between the original sound and its repetitions is too short for the ear to appreciate.

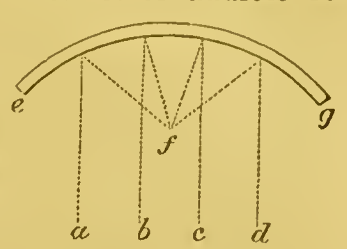
It is worthy of remark, that a small apartment or confined space with parallel walls has a certain musical note proper to it, heard after any blow, as of a hammer, the pitch of which

depends upon the number of pulses or repetitions of a sound produced there in a given time by the returns from its walls. The velocity of sound being uniform, this number must depend on the size of the apartment.

There is a curious effect of echo which both illustrates the nature of the phenomenon, and proves that a tone or musical sound is merely a repetition of pulses following each other very quickly and at regular intervals. Iron railings are generally formed of square bars, of which the sides are plane surfaces, and may produce echoes. A sound therefore, such as the sharp blow of a hammer, occurring near the end of such a railing, is echoed to a corresponding place on the other side by every bar in it; and as the echoes do not return all at once, but in regular succession according to the increasing distances of the bars, the consequent regular succession of slight pulses, with uniform and small intervals, affects the ear of a person fitly placed, not as the echo of a single blow, but as a continued musical tone, the pitch of which depends on the distance of the bars from each other.—The writer of this had observed, in passing on horseback along a particular portion of road, where there were first a length of plane wall and then two lengths of wooden paling with rails or bars overlapping at the edges, and the rails of one length being narrower than those of the other,—that as he neared the palings there was a clear echo of the horse's cantering feet, and also a ringing sound for every step of the horse. He at first concluded that the road there was singularly hard, although that did not appear, and he slackened the horse's pace, until observing one day that the ringing sound was of different pitch near the two pieces of paling, and so as to correspond with the different width of the rails, the true explanation occurred to him that the sound was an echo of the nature above described.

778. That an echo may be perfect, the surface producing it must be smooth, and of some regular form; for the wave of sound rebounds according to the same law as a wave of water, or a ray of light, or an elastic ball, &c., as explained in Art. 202, *viz.* perpendicularly to the surface at the part, if it fall perpendicularly, but if it fall obliquely from one side, departing with an equal degree of obliquity on the other. To express this very important law shortly, it is said that "the angle of reflection is equal to the angle of incidence."—According to this law, an irregular surface must break an echo; and if the irregularity

be very considerable, there can be no distinct or audible reflection at all. A regular concave surface, on the contrary, as *e g*, may concentrate sound, and bring all which falls upon it, as from *a b c d*, to nearly the same centre or *focus*, as at *f*, so as to produce there a very powerful effect.

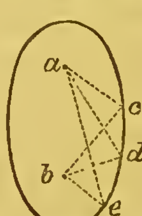


We thus see the reason why echo is much less perfect from the front of a house which has windows and doors, than from the plane end, or any plane wall of the same magnitude,—and why the resonance of a room is so irregular and indistinct when the room contains curtains, carpets, and other furniture, or a crowded assembly. Halls for music have generally plane walls. Theatres for the drama, again, have boundaries broken in all ways by rows of boxes, and various ornaments, that distinct echoes may not mix with a speaker's words.

The concentration of sound by concave surfaces produces curious effects both in nature and in art.

There are remarkable situations where the sound from a cascade is concentrated by the surfaces of a neighbouring cave so completely, that a person accidentally bringing his ear into the focus, is suddenly astounded, as if all nature were crashing around him. A chair placed in the cave, so that a person sitting down in it has his ears in the focus, insures the success of the intended surprise.

779. The centre of a circle is the focus in which sound issuing from it is again collected after reflection: hence the powerful echo near the centre of a round apartment. An *oval* has two centres or *foci*—one towards each end, as *a* and *b*—and the nature of the curve is such, that sound, or light, or heat, spreading around from either of the foci, as *a*, by obeying the law of reflection above stated, is all directed from the various points, as at *c d e*, &c., to the other focus, as at *b*. Hence a person uttering a whisper in one focus of an oval room is very audible at the other, although he may not be heard by persons placed anywhere else. Such a room may be called a *whispering gallery*. Concave surfaces facing each other, as two alcoves in a garden, or covered recesses on opposite sides of a street or bridge, will enable persons seated in their foci to converse by whispers across louder noises in the



space between, and without being themselves overheard in that space.

The reason why a tube conveys sound so far, is, that its sides confine or repress, by a continued reflection, the advancing sound which in the open air would quickly spread laterally and be dissipated. And the reason that the plane surface of a smooth wall, or of water, &c., also conveys sound so far is, that it similarly prevents the lateral spreading and dissipation, although only on one side.—Persons far apart may converse along a smooth wall.—The barking of dogs, or the clear voice of a street-crier, in a town situated on the border of a lake, may be heard across the water in a calm evening, at a distance of miles, as the writer one evening perceived near Southampton—the sound of bells, of course, is audible much farther.—And in the stillness of night, even the splashing oars of a boat will announce its approach to persons waiting at a great distance.

If a wall be curved inwards, or concave, it not only prevents the spreading outwards of any sound which passes along it, but is constantly condensing the sound waves by driving the external part inwards. Hence, in a circular space, such as a gallery under a dome, as in St. Paul's Cathedral, persons close to the wall may whisper to each other at great distances.

780. An *ear-trumpet* is a tube wide at one end where the sound enters, and narrow at the other where the ear is applied: its sides are so curved that, according to the law of reflection, any sound which enters is condensed towards the narrow end. It may so increase the intensity of sound which reaches the ear through it, that persons who from any accident have had their acuteness of hearing impaired, may obtain from it such aid to the ear as spectacles give to the eye.

781. The concave hand held behind the ear aids in a considerable degree as the ear-trumpet does, as may be judged by observing almost any ordinary assembly of listeners, particularly if the speaker has a weak voice or is distant. It may appear strange then that so good a substitute for the hand as is a small concave cup of wood or other light material, or, better still, two such cups joined by an elastic wire and worn as a pair of spectacles are, is not universally used, wherever the need for such assistance exists. The writer of this, during a journey by railway at night, when a window was improperly opened upon him, had inflammation of the throat induced, which spread to the ear and dulled the sense. Finding how useful

the hand held behind the ear was, and reflecting that many animals have the power of turning the ears towards any source of sound, he procured two small flat wooden cups, and joining them by a wire, put them on as described. The result was very satisfactory. He found further that when pressing these cups forward by the hands against the backs of the ears, or keeping them so forward by a band crossing in front, the useful effect was much increased. The various forms of ear-trumpet act more powerfully than this combination, particularly the long flexible tube with a small trumpet-opening to be held near the mouth of the speaker, while the hearer places the other end to his ear; but all these occupy inconveniently the hands of one or of both parties, while the ear-shells no more incommode than a pair of spectacles.

A notorious instance of a sound-collecting surface was the *ear of Dionysius*, in the dungeons of Syracuse: the roof and walls of the prison were so formed as to collect the words and even whispers of the unhappy prisoners, and to direct them along a hidden conduit to where the tyrant sat listening. The wide-spread sail of a ship, rendered concave by the breeze, is also a good collector of sound. It happened on board a ship sailing south in the Atlantic, towards Rio de Janeiro, while yet far from the destined port, and out of sight of land, that one day, persons on the deck, when near a particular part of it, thought they heard distinctly the sound of bells, varying as in human rejoicings. All were attracted to listen, and the phenomenon was mysterious. Weeks afterwards it was ascertained that at the time of observation the bells of the city of St. Salvador, on the Brazilian coast, had been ringing on the occasion of a festival: their sound, therefore, favoured by the wind at the time, had travelled over at least 100 miles of smooth water, and had been brought to a focus by the concave sail in the particular situation on the deck where it was listened to. It appears from this that a great concave might be constructed having a like relation to sound that a telescope has to light. A gentleman on the 18th of June, 1815, while sitting by the wall of his garden, on the heights near Dover, believed that he heard distinctly the firing of the cannon at the great battle then raging in Belgium.

The *speaking-trumpet* is made according to the same law of reflected sound, with the view of directing the strength of the voice to a particular point. The sea captain uses it to hail ships

at a distance, or to send his orders aloft, where the unaided voice would be lost in the noise of the wind and waves. A similar form of mouth is used for the military trumpet, and fits it to be useful even amid the uproar of battle.

Some amusing effects have been produced by operating on sounds with tubes and concave surfaces. What was termed the *invisible girl*, was an arrangement whereby the questions of visitors were caught in a concealed concave, and carried to the director who sat at a distance; and his replies through a fit channel, became audible to the inquirers alone.

The concave, undulating, and perfectly smooth internal surface of many sea-shells, fits them to catch, mix, and return the pulses of sounds that happen to reach them, so as to produce that curious resonance from within, which closely resembles the sound of the distant ocean—so closely, that the spirited boy, after reading with delight the stories of voyages which paint dangers to be nobly braved, and wonders of nature to be seen in distant lands, fans his imagination with this voice of the shell, and deems himself already away among the billows.

782. *The animal ear,*

so admirably adapted to perceive the evanescent tremblings of the air, has of course a structure in most exact relation to their nature as now explained. The parts of the ear, and the progress of sound to the sentient nerve, may be simply sketched as follows.

1st. There is external to the head, a wide-mouthed tube or ear-trumpet *a*, for catching and concentrating the waves of sound. In many animals it is moveable, so that they can direct it to the place from which the sound comes.

2nd. The sound concentrated at the bottom of the ear-tube, falls upon a membrane stretched across the channel, like the parchment of an ordinary drum, over the space called the *tympanum* or *drum of the ear*, *b*, and causes the membrane to vibrate. That its motion may be free, the air contained within the drum has free communication with the atmosphere, by the open passage *f*, called the *Eustachian tube*, leading to the back of the mouth. A degree of deafness ensues when this tube is obstructed, as by thick secretion; and a crack or sudden noise, with immediate return of natural hearing, is generally expe-

rienced when, in the effort of sneezing, or otherwise, the obstruction is removed.

3rd. The vibrations of the membrane of the drum are conveyed farther inwards, through the cavity of the drum, by a chain of four bones (not here represented on account of their minuteness), reaching from the centre of the membrane to the *oval door* or *window* leading into the labyrinth *e*.

4th. The labyrinth, or complex inner compartment of the ear, over which the nerve of hearing is ramified, is full of liquid; and therefore by the law of fluid pressure, when the force of the moving membrane of the drum, acting through the chain of bones, is made to compress the water, the pressure is felt instantly over the whole cavity, as in a hydrostatic press.—The labyrinth consists of the *vestibule*, *e*, the three *semicircular canals*, *c*, imbedded in the hard bone, and a winding cavity, called the *cochlea*, *d*, like that of a snail-shell, in which fibres, stretched across like harp-strings, constitute the *lyra*.—The separate uses of these many parts are not yet perfectly known, but each, doubtless, has its use and purpose. The membrane of the tympanum may be pierced, and the chain of bones may be broken without entire loss of hearing. Considerable diversity of form and dimension is found in the ears of different animals. The bone containing the cavities of the ear is the hardest in the body, and is the first formed.

The ear has the power of judging of the direction in which sound comes.—A person in a thicket listening to the song of various birds, although they be concealed from his eye by the luxuriance of foliage, still judges correctly by the ear in what tree every little songster is concealed. — The same truth is strikingly exemplified in the fact that, when horses or mules march in company at night, those in front direct their ears forwards; those in the rear, backwards; and those in the centre, laterally or across;—the whole troop seeming to be actuated by one feeling, which watches the common safety.

The intensity of sound is to the ear a measure of distance.—In a windy night, the sound of a distant bell may be brought so quickly, that it has not yet had time to spread and be weakened; and a person is often roused from a reverie by its unusual loudness and apparent nearness.—When a stormy wind blows directly upon a coast, and the swollen waves roll furiously upon the sandy beach or among the rocks, the countryman living far inland hears the uproar, almost as if the ocean had burst its

barriers, and were pouring in upon the land.—The scene-contrivers at our theatres heighten the illusion of an approaching procession, by letting the accompanying music be first heard from a closed chamber or with feeble tones, and afterwards with gradually increasing loudness. To the imagination, already excited by the suitable drama, the advancing host is thus most vividly portrayed; and when at last, with the thunder of drums and trumpets from the front of the stage, the crowd also appears, the desired effect is complete.—It is the varying loudness of an Æolian harp which produces the feeling that the heavenly choir is sometimes approaching and sometimes receding.

PART III.

(CONTINUED.)

SECTION V.—DOCTRINES OF FLUIDITY IN RELATION TO ANIMALS.

783. At the end of the chapter on the Mechanics of Solids at page 144, a section is added entitled *Animal Mechanics,* setting forth facts important to be known by everybody respecting the solid framework of their bodies. Here, at the end of the chapters on the Mechanics of Fluids, a section is added which may be entitled Animal Hydrostatics, Pneumatics, Acoustics, &c., respecting the phenomena of fluidity in the living body, and equally important to be studied by all.

ANALYSIS OF THE SECTION.

1. The Circulation of the Blood.—*There is constantly streaming from the heart to all parts of the animal body that red opaque fluid, the blood, carrying fresh nourishment to the various tissues and organs, and taking from them the results of tear and wear, or old material which has served and has to be carried away. The motion is kept up by the pumping action of the heart, forcing the blood along the tubes called* arteries, *which gradually ramify to reach every spot, through the extreme branches, called from their minuteness* capillaries, *into a corresponding tubular system called* veins, *which carry it back to the chest to be purified and renewed.*
2. Respiration or Breathing.—*The chest is a cavity which alternately expands and contracts like a pair of bellows, thereby taking in and again expelling a certain volume of atmospheric air. This air comes nearly into contact with every particle of the circulating blood as that passes at every revolution through the spongy lobes of the lungs which occupy the chest. These lobes consist chiefly of delicate air-cells and minute capillaries, so thin that air can act through their substance. Great changes are produced in the blood by the manner of contact described, and the animal warmth is one of the effects.*
3. Voice and Speech.—*The air which enters the chest as breath, while re-issuing, is caused, at the will of the person, to produce sound. This, modified by changed action of the parts in and about the mouth, becomes*

distinct articulations or words, giving to man the faculty of speech, through which the noble faculties of his mind manifest themselves and operate.

4. Conversion of the Food into New Blood.—*The food on entering the mouth is broken down and soon half liquefied by mixture with saliva, gastric juice, &c. As it then passes along, in the intestinal canal lower down, what of it is fit to become blood is absorbed by the lacteal vessels, and carried by them to mingle with the blood returning in the great veins towards the heart.*

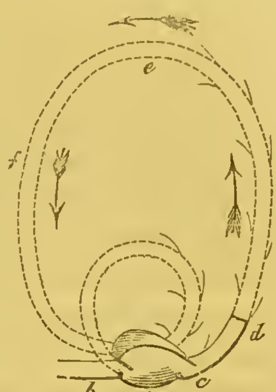
The Circulation of the Blood.

784. There are few things more remarkable in the history of the progress by which man has arrived at his present knowledge of nature, than that, until about 250 years ago, he was ignorant of the fact that the blood in his own and in other animal bodies is constantly travelling from the heart to all other parts, and back again. This truth was at variance with strong appearances, and the most fixed prejudices. It fell to the lot of our countryman, Dr. Harvey, to make the discovery, and he was led to it from having more extensive knowledge of mechanical philosophy than was common among his professional brethren at the time. He published his proofs in the year 1619. A person who tries to imagine what the science of medicine could have been while it took no account of this fact, on which, as a basis, nearly all the certain reasoning about the phenomena of life must rest, is prepared for what old medical books exhibit of the writhings of human reason, in attempts to account for numerous facts, or to form theories, while a fatal error was mixed with every supposition.—The chief circumstance which prevented the earlier discovery of the circulation was, that on examining dead bodies, the arteries were always found to be without blood in them, while the veins were charged with it; which was the reason, also, of the first-named vessels being called *arteries* or *air-tubes.*

785. We now know, that as water from a central source spreads over a large city in pipes, to supply the inhabitants generally, and to answer the particular purposes of brewers, bakers, tanners, and many others, the remainder passing away in drains towards the general reservoir of the ocean; so nearly, in the human body, does the blood spread from one centre, the heart, through the arteries, to nourish all the parts, and to supply material of secretion to the liver, the kidneys, the sto-

mach, and other viscera. It then returns from these by the veins towards the chest and lungs, to be purified and to have its waste replenished, that it may again renew its course.

786. In the water-works of a city, the motion is given by a pump-barrel and piston, worked by steam-power. In the human body the pump of the blood is the heart, a strong muscular bag, which relaxes to let blood enter through a valve at one side, and then, by contracting, forces it out again through a valve on the other side into the arterial tube, which carries it forward. This kind of action is well illustrated by the common caoutchouc-bag syringe, A, worked by the force of a hand squeezing it. The bag, A, is of the size of an orange. Its entrance-tube, *b*, if immersed in water, admits the charge through the valve at *b*, which then shuts to prevent any return. On then squeezing the bag with the hand, the water in it is forced out through the valve *c*, and jets from the end of the tube *d*. On ceasing to squeeze, the bag is re-filled from *b*, while the valve *c* prevents the return of what had already passed through. If an elastic tube, as sketched here by the dotted lines *d e f b*, be added to form an open communication between the two orifices of outlet and inlet, and if the hand then contract at intervals like the beats of the heart, a strong current or circulation of the water through the bag and tubes will be produced, like that of blood in the living body,—with this difference, that the channels of departure and return in the syringe are single tubes, but in the body are tubes with innumerable branches, of which the extremities, of capillary size, open or inosculate into one another. It is further to be noticed, with respect to the circulation in warm-blooded animals, that there are really two distinct hearts, although so connected as to appear one: the first, on the left side, serves the purposes of the general circulation; the other, on the right side, receives all the dark-coloured blood returning from the general circulation, and sends it through the shorter circulation of the lungs, where it is purified, reddened, and refreshed by the pure air entering there as breath, before it again enters the heart of the general circulation.



The Pulse is merely the sudden gush of blood driven into the great trunk of the arterial tree, the aorta, by the sudden con-

traction of the heart, causing an undulation over the whole system.

787. Among the facts in nature offered to man's observation, there is perhaps nothing more marvellous than that, out of the same red opaque fluid, the blood, which, if drawn from a vein and allowed to stand at rest, is quickly turned into a soft coagulum, the living powers in the body should find and separate from the mass the materials of which all other things in and about the body are formed. How strange that these powers can thence obtain the pure watery tear which constantly keeps the eyeballs moist and clean—the colourless saliva, perspiration, gastric juice, as well as the bile and other coloured secretions—and should further obtain also the materials of solid flesh, skin, hair, nails, of the hard bones, and of the enamel of the teeth; and stranger still that, after finding the fit materials, they should be able therewith to construct such curious and complex organizations, as of the eye, the ear, the brain, the heart. Then we see, in all the inferior races of animals, the like phenomena going on. Out of the blood of the creatures are formed the teeth and claws of the tiger, the proboscis of the elephant, the feather of the peacock. And, completing the series of wonders, it may be noticed that each species of animal, in search of the food which is to make its blood, errs not as to the kinds which will yield the ingredients required.

788. *Force of the heart and motion of the blood in the arteries.*

The contractions of the heart inject the blood into the arteries with a force maintaining such a tension in them, that, according to the interesting experiments of Dr. Hales, recorded in his *Statical Essays*, if any artery of a large animal like a horse be made to communicate with an upright tube, the blood will ascend in the tube to a height of about ten feet above the level of the heart, and will there continue, rising and falling a few inches with each pulsation of the heart. Now a column of *ten* feet, as explained in Art. 437, indicates a pressure of about *four and a half* pounds on a square inch of surface: this, therefore, is the force of the heart urging the blood along the arteries and through the capillaries into the veins.—The tension of the veins is much less, because of the resistance offered by the capillaries, as will be explained under the proper head, and because the blood readily escapes from the veins into the heart.

Hales found that in a tube communicating with a vein, the blood stood only a few inches higher than the level of the heart. In small animals he ascertained the tension of artery and vein to be less than in large ones; and the ratios deduced for the human body, under ordinary circumstances, were eight feet column, or nearly four pounds per inch for the arteries; and half a foot column, or a quarter of a pound per inch for the veins.

Passage of the blood through the capillaries.

789. We have seen above that the heart keeps up a tension or pressure in the arteries, of about four pounds on the square inch of their surface; and with this force, therefore, is propelling the blood into the capillaries. If these last were passive tubes, constantly open, such force would be sufficient to press the blood through them with a certain uniform velocity: but they are vessels of great and varying activity: it is among them that the nutrition and repair of the different textures of the body takes place, and that all the secretions from the blood are performed, as of *bile, gastric juice* or *saliva*, &c.; and to perform such varied and often fluctuating offices, they require to be able to control, in all ways, the motion of the blood passing through them. The capillaries of the cheek, under the influence of shame, dilate instantly, and admit more blood, producing what is called a *blush;*—under the influence of anger or fear, they suddenly empty themselves, and the countenance becomes pallid—tears or saliva, under certain circumstances, gush in a moment, and in a moment again are arrested. If a person having inflammation in one hand be blooded from corresponding veins in both arms at the same time, twice or thrice as much blood will flow from the diseased side as from the other. Similar changes occur in many other instances. Now the action of cylindrical vessels, capable of causing these phenomena, is contraction and dilatation of their coats; and with reference to such action it merits notice, that arterial branches have more of the fibrous or contractile coat, in proportion as they are smaller.

A muscular capillary tube strong enough to shut itself against the arterial current from the heart, is strong enough also to propel the blood to the heart again through the veins, even if the resistance on the side of the veins were as great as the force on the side of the arteries. For if we suppose the first circular fibre of the minute tube to close itself

completely, it would, of course, be exerting the same repellant force on both sides, or as regarded both the artery and vein. If then the series of such fibres forming the tube were to contract in succession towards the vein, as the fibres of the intestinal canal contract in propelling the contents of that canal, it is evident that all the blood in the capillary would thereby be pressed into the vein towards the heart. If after this the capillary again relaxed on the side of the artery, so as to admit more blood, and again contracted towards the vein as before, it would produce a forward motion of the blood, first towards the vein, and then in it, independently of the heart, and might carry on a slow circulation if there were no heart.

790. It is capillary action which absorbs and moves the fluids of the classes of animals which have no heart. It must also be the power which moves the blood in warm-blooded monsters formed without hearts. There are cases of apparent death among human beings, where the heart remains inactive for days, and yet a degree of circulation sufficient to preserve life is carried on by the capillaries. In illustration of capillary action, we have also the absorption, by the lacteals, of nutriment from the alimentary canal; and perhaps, to a certain extent, the circulation of the blood in the livers of animals. In this last case, the blood collected by veins from the abdominal viscera, instead of going directly to the heart, is again distributed through the liver by the branches of the *vena portæ*, and is then again collected by the ordinary veins of the liver, and carried to the heart: it thus moves through two sets of capillaries in passing from the arteries to the heart again.

791. The action of the capillaries is the cause of that singular fact which prevented the ancients from discovering the circulation of the blood, *viz.* the empty state of the arteries after death. All the muscular parts of an animal, including, therefore, the contractile coats of vessels, retain their life, or power of contracting, for a considerable time after respiration has ceased,—as is seen in the recovery of persons apparently drowned or suffocated; in the leaping of a heart taken from an animal recently killed; in the actions resembling life which can be produced, by the agency of galvanism, in a body recently dead: but the fact is seen still more aptly for our purpose, in the total disappearance of a local inflammation after the death of the patient. Inflammation involves a gorging or over-disten-

sion of the capillaries, and when the heart has ceased to press blood into them, the contractile force remaining in them, even under disease and in a dead animal, is sufficient to squeeze the blood out of them, and often to remove all trace of the malady which has been fatal.—In ordinary cases, then, the capillaries throughout the body remain alive and active for a considerable time after breathing has ceased, working like innumerable little pumps, and emptying the arteries into the veins. As the red blood is their proper sustenance as well as stimulus, they work as long as there is any of it coming into them from the arteries behind; except, however, the capillaries of the lungs, which soon cease to act, because, after breathing has ceased, they receive only black blood, and are moreover compressed by the collapse of the chest; and all the blood accumulates behind them. The capillaries may continue to be filled from the arteries, either in consequence of their elasticity opening them with what is called a suction power, or of an absorbent power dependent on life, like that of the lacteals and of the absorbents all over the body, and like that, of the vessels in the roots of vegetables. When death is produced by lightning, or by the poisons which destroy all muscular irritability, and therefore that of the capillaries, the arteries after death are found to contain blood like the veins. In a living body, if an artery be tied, the part beyond the ligature is soon emptied into the veins, and becomes flat.—This experiment has been made even upon the aorta itself.

792. The empty state of the arteries after death has been ascribed, by some teachers, to the momentum with which they supposed the blood to be thrown out from the heart in its last contraction,—sufficient, said they, to squirt it fairly through the most distant capillaries; a doctrine exemplifying the carelessness with which men sometimes receive and repeat opinions, to which their attention has never been fully awakened. Such an effect would not follow, even if the action of a dying heart were very much stronger; while, in reality, it is in most cases so feeble, that the pulse for some time ceases to be perceptible at the extremities, and the diminished circulation lets them become cold.—Other physiologists have taught that an artery is capable of contracting directly upon its contents, so as to expel even the last drop;—but large arteries, when emptying, do not contract *roundly* like an intestine: they become *flat* like elastic tubes of leather *sucked* empty, and no contractile action of the

vessel itself could bring its sides together in such a manner. If arteries emptied themselves by their own action, the pulmonary artery should be more certainly empty than the aorta, because it is shorter: yet it is always full; for the reason already stated, that the pulmonary capillaries cease to act after respiration has ceased, on account of the blood in them being venous or dark blood, and therefore not life-supporting or stimulant to them.

Passage of blood through the veins.

793. The veins have much thinner coats than the arteries, and if taken altogether have much greater capacity: for besides being larger than the corresponding arteries, they exist, in many situations, as double sets, an exterior and an interior: they have also very frequent inosculations or communications with each other throughout their whole course, and there are in many places folds of the internal coats which act as valves, allowing a current in only one direction.

The simple weight of the column of blood in any descending artery is just sufficient to raise the blood through open capillaries to an equal height in the corresponding vein, according to the hydrostatical law, that fluids attain the same level in all communicating vessels; and therefore, as the arch of the aorta rises considerably above the heart, the gravitating pressure of the descending arterial column of blood would be sufficient to lift that in the veins not only up to the heart, but considerably beyond it. In addition to this influence of gravity on the venous current, the blood is pressed into the arteries, and from them therefore towards the veins, with a force from the heart itself, as stated above, of about four pounds to the square inch, or, in other words, as if there were a column of blood eight feet higher than the heart urging the current. It might be expected from the law of equal diffusion of pressure in fluids, that these causes would soon produce a tension in the veins as great as in the arteries: and this does not happen, only because the blood has a ready escape from the veins through the right auricle and ventricle of the heart. Under ordinary circumstances, there can be no greater tension in the veins than what is sufficient to lift the blood to the level of the heart and to overcome the friction.

These facts, then, and others that might be mentioned, prove incontestably that the blood is pressed into the veins from the

arteries and capillaries, with force sufficient to lift it, not only to the heart again, but many feet farther, *viz.* about as far as it would ascend in a tube rising from the tense arteries themselves. So little, however, has this important truth been understood, that in elementary works of authority lately published, the venous current is treated of as a very obscure subject; and some authors, in their anxiety to explain it, have assigned causes for it which are positive absurdities in physics. The difficulty in the question seems to have arisen from the great disparity observed between the tension in the arteries and in the veins, while the reflection did not occur, that the disparity was owing to there being a free passage or outlet from the veins through the heart.

A knowledge of the facts detailed under the three heads of *arteries, capillaries,* and *veins*, prepares us for the discussion of the following subjects.

The force of the Heart.

794. The arterial tension of four pounds to the square inch, marked by its supporting in a tube connected with the arteries, a column of blood eight feet high (*see* Art. 788), is produced by the action of the heart; but as the heart, while injecting the blood against this resistance, has moreover to overcome the *inertia* both of the quantity injected, and of the mass in the great artery, first moved by the injection, as also the resisting *elasticity* of the vessel which yields to momentary increase of pressure, the heart must act with a force exceeding four pounds on the inch. And as the left ventricle of the human heart, when distended, has about ten square inches of internal surface, the whole force exerted by it is a matter of simple calculation.

795. Some physiologists have expressed surprise that the force of the heart should be so great as it is, remarking that much less would have sufficed to propel the blood to the most distant capillaries; but they did not reflect that the heart, besides carrying on the general circulation, has to force blood into those parts of the flesh which in the various positions of sitting, lying, standing, &c., are for the time compressed by the weight of the body above; for that, if it were not strong enough for this purpose, either the compressed parts, deprived of their nourishment, would quickly die, or the person, obliged to be every moment changing position, could obtain no lengthened repose. In illustration of this point, we may advert to the frequent occurrence,

2 A

in diseases where the power of the heart is for the time weakened, of sloughings, or bed-sores in the bearing parts, bringing many cases of illness to terminate fatally, which would otherwise soon have terminated in health.—The author of this work has had great satisfaction in suggesting a means of entirely preventing such deplorable terminations, namely, that which he is now about to describe under the title of

The HYDROSTATIC *or* FLOATING BED *for Invalids.*

796. In many of the diseases which afflict humanity, more than half of the suffering and danger is not really a part of the disease, but the effect or consequence of the confinement to which the patient is subjected. Thus a fracture of the bone of the arm is as serious a local injury as a fracture of one of the bones of the leg; but the former leaves the patient free to go about and amuse himself, or attend to business as he wills, and to eat and drink as usual—in fact, hardly renders him an invalid; while the latter imprisons the patient closely upon his bed, and brings upon him, first, the irksomeness of the continued position, and then the pains of the unequal pressures borne by the parts on which the body rests. These, in many cases of confinement, disturb the sleep and the appetite, and excite fever, or such constitutional irritation as much to retard the cure of the original disease, and not unfrequently to produce new and more serious disease. That complete inaction should prove hurtful to the animal system, may by all be at once conceived; the operation of the continued local pressures will be understood from the following statements. The health, and even life, of every part of the animal body, depends on the sufficient circulation through it of fresh blood, driven in by the force of the heart. Now when a man in health is sitting or lying, the parts of his flesh compressed by the weight of the body, do not receive the blood so readily as at other times; and if from any cause the action of his heart has become weak, the interruption will both follow more quickly and be more complete. A peculiar uneasiness soon arises where the circulation is thus obstructed, impelling the person to change of position; and a healthy person changes as regularly, and with as little reflection, as he winks to wipe and moisten his eyeballs. A person weakened by disease, however, while he generally feels the uneasiness sooner, as explained above, and therefore becomes what is called restless,

makes the changes with much fatigue; and should the sensations after a time become indistinct, as in the delirium of fever, in palsy, &c., or should the patient have become too weak to obey the sensation, the compressed parts are kept so long without their natural supply of blood that they lose their vitality, and become what are called sloughs or mortified parts. These have afterwards to be thrown off, if the patient survive, by the process of ulceration, and they leave deep holes, requiring to be filled up by new flesh during a tedious convalescence. Many a fever, after a favourable crisis, has terminated fatally from this occurrence of sloughing on the back or sacrum; and the same termination is common in lingering consumptions, palsies, spine diseases, &c., and generally in diseases which confine the patients long to bed.

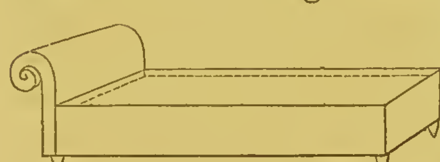
It is to mitigate all, and entirely to prevent some of the evils attendant on the necessity of remaining in a reclining posture, that the hydrostatic bed serves. It was first used under the following circumstances.

797. A lady after an accident had a premature confinement, followed by low fever, and she fell into a state of such muscular weakness as to have the appearance of universal palsy. She could scarcely move a hand or even a finger, and she could not of herself change in any degree her position in bed. Her voice was so weak that only an ear close to her could understand what she said. This muscular weakness affected the heart as much as the other muscles; her pulse could scarcely be felt, and the heart had not power sufficient to force blood into the parts of the flesh which happened to be undermost and compressed by the weight of the body over them; consequently these parts, deprived of their nourishment, became painful, and caused her to be moaning out constantly, "Oh, turn me!" The skin on the more protuberant parts began to ulcerate, and soon there were open sores on the sacrum, hips, and heels, which required surgical treatment. She was placed on the bed devised for such invalids by the eminent surgeon of St. Bartholomew's Hospital, Henry Earle, and Mr. Earle himself gave his valuable aid. The bed was furnished with pillows of down and air, and opposite to the sloughing parts the mattress was cut out to avoid pressure. The remedial means tried, all failed to check the unfavourable progress, and there seemed to be no room for hope.

798. Under these circumstances the idea of the floating bed came vividly to my mind. It was evident that in this case any

pressure on the flesh greater than that borne by a person lying in a bath could not be borne. I said to the professional friends in consultation with me, that as a water-fowl resting on the face of a pond has the support first of its own soft feathers, and under that the still softer support of the water, such exactly would be the support given to a human being laid on a floating mattress. If, therefore, a water-tight trough were taken of the dimensions of a common sofa, into which a few inches depth of water were poured, and if over this a sheet of India-rubber cloth of the kind which bears the name of Macintosh were thrown, on which then folded blankets or a thin mattress were laid, a bed might be made not distinguishable from a common bed but by its surpassing softness. This proposal was approved of, and immediately acted upon. The trough was made in the course of the night, and at six o'clock on the following morning Mr. Earle and I attended to see the sufferer placed upon it. As Mr. Earle lifted her from the old bed to the new, he said, "I have lifted you so that I am obliged to lay you down first on your side, but I will raise you again to place you on your back," her reply was, "Do not touch me, for I am quite at ease." She was therefore left so. She soon fell into a calm sleep, which lasted for nearly four hours. She awoke singularly refreshed, and took nourishment. From that time the character of the sores immediately changed, the sloughs were thrown off, and within six weeks all were healed. I visited her soon after at the Isle of Wight, to which place she had removed. About two years after this, exposure to cold caused an attack of erysipelas, which was fatal to her. She was then at a distance from me.

799. The first trough made for this case (which I retain in my house fitted up as a sofa) was found to be for some purposes not quite broad enough, and soon after a wider one was substituted, having the appearance



here sketched. It was six feet long, nearly three feet wide, and eleven inches deep, lined with metal, and half filled with water. Over it a large sheet of caoutchouc cloth was thrown, wide enough to be a complete lining to it when empty. This sheet had its edges touched with a varnish to prevent the moisture from creeping round by capillary attraction, and was secured to its place in a water-tight manner, all round the upper

border of the trough, to prevent displacement, or spilling of the water.

800. Very numerous cases, more or less like that above related, have since occurred, of recovery from apparently hopeless states by the use of the bed, and the numbers would have been much greater, but for a misconception still common that a water pillow laid on a flat surface is a nearly equivalent substitute for the floating bed. There was no clear notion of the nature of hydrostatic support or floating, and the common erroneous belief was, that the weight of the person resting on the bed was supported partly by the strength and tension of the caoutchouc sheet. Then the considerable cost and bulk of the complete bed were reasons with many for adopting any cheaper and smaller apparatus which was thought to answer in a degree the same purposes. The author's professional engagements did not allow him, after the fifth edition, to complete and republish his work on Physics, and to describe therein, as he does now, simpler modifications of the bed, convenient for certain purposes. These, however, although not so completely before the public as in the volume on Physics, were known and used by many members of the profession. The disappointments from the use of the water cushion, where the bed would have accomplished all that was desired, led many persons to deem the failure of the eushion a failure of the principle of the bed. This will now be understood after reading the following paragraphs.

801. It may be here recalled to mind, that the human body is nearly of the specific gravity of water, or of the weight of its bulk of water, and therefore, as is known to swimmers, is just suspended or upheld in water without exertion, when the swimmer rests tranquilly on his back with his face upwards. He then displaces water equal to his own body in weight as well as in bulk, and is supported as the displaced water would have been. If his body be two and a-half cubical feet in bulk (a common size, a foot of water weighing sixty-two pounds and a-half), he will just displace two and a-half cubic feet of water, equal in weight to his body. If, however, instead of displacing the water with his mere body, he choose to have something around or under him which is bulky with little weight, as pieces of cork or the mattress of the bed above described, kept dry, then, after his weight has forced two cubical feet of that under the level of the water, he will float with four-fifths of his body above the level, and will sink much less into his floating mattress than a person

sinks in an ordinary feather bed. It thus appears that by choosing a certain thickness of mattress, and if unusual positions are required, by having different thickness in different parts, or by placing a bulk of folded blanket or of pillow over or under the mattress in certain situations, any desired position of the body may be easily obtained.—If the water be about six inches deep, which in general suffices, the person standing upon any part of the bed, or sitting with the knees raised, will cause the part of the mattress on which he rests, gently to touch the bottom, because a narrow end of the body cannot displace water equal in weight to the whole, but even then the person is as if standing or sitting on a softened support. If it be desired to prevent the mattress, when used as a seat, from touching the bottom, the object may be attained by placing a thick cushion there, or by having under the middle of the mattress a broad band or strap fixed to one edge of the trough, and connected with the other by buckles or otherwise, so as to be tightened to allow the mattress to descend just so far, and no farther.

802. This bed is a warm bed, owing to water being nearly an absolute non-conductor of heat in the direction from above downwards, and owing to its allowing no passage of cold air from below. From this last fact, however, less of the perspiration, sensible and insensible, would be carried off by the air than in a common bed, which allows some air to pass through its substance, and there arises a necessity for ventilation to prevent the perspiration from being condensed as dew on the surface of the water-sheet below. This ventilation is perfectly and cheaply obtained by placing under the mattress, or as part of it, a cloth having arranged on it, like the bars of a gridiron, small flexible tubes of tinned wire wound spirally, with the ends of the tubes open to the atmosphere, either directly or through two larger tubes crossing and uniting their extremities near the ends of the mattress, and then issuing at the corners of the bed from under the clothes. Through these tubes it is possible not only to ventilate with any desired rapidity, but to regulate the temperature if desired for any special purposes, by letting the entering air be of the desired temperature, as explained in the Section on Heat. This bed is in itself as dry as a bed can be, for the India-rubber cloth is quite impermeable to water. Unlike any other bed, it allows the patient, when capable of only feeble efforts, to change his position, almost like a person floating in a bath, and so, to take a degree of exercise, affording the kind of

relief which persons in a constrained position obtain by occasional stretching, or which an invalid seeks by driving out in a soft-springed carriage. It exceedingly facilitates turning for the purpose of dressing wounds, for by gently raising one side of the mattress or depressing the other, or merely by the patient's extending a limb to one side, he is gently rolled over, nearly as if he were simply supported in a water-bath; and it is possible even to dress wounds, apply poultices, or place vessels under any part of the body, without moving the body at all; for there are some inches of yielding water under the body, and the yielding mattress may at any part be pushed down, leaving vacant space there, without the support being lessened for the other parts.

803. With this bed, evidently, the fatal termination called sloughing, or bed sores, now very common in fevers, and other diseases, need not occur at all. And not only can it prevent such termination, but by alleviating the distress through the earlier stages, it may prevent many of the cases from ever reaching the degree of danger. This bed used without the mattress, acts in some respects like a warm or a cold bath, without allowing the body to be touched by the water; and in India it might be used as a cool bed for persons sick or sound, during the heats which there prevent sleep and endanger health.

804. There are numerous other professional adaptations and modifications of the principle of the bed, which will readily occur to practitioners sufficiently versed in the department of natural philosophy (hydrostatics) to which it belongs. Of these the author intends in a professional Appendix, published separately, to give a much fuller account than was contained in the former editions of this work. Before reflection a person readily supposes a resemblance to exist between the hydrostatic bed and an air-bed or cushion, calling this a water-bed or cushion; but the principles of the two are very distinct, not to say opposite. An air pillow supports altogether by the *tension of the surface* which encloses the air, and is therefore somewhat like a naked hammock or the sacking under the straw mattress of a common bed, and really may be a very hard pillow; but in the hydrostatic bed, there is no tense surface or web at all: the patient is floating upon the water, on which a loose sheet partly in folds is lying between him and it, merely to keep the mattress dry, and every point of his body is supported by the water immediately beneath it. To recall the difference here described, and which is all-important, the bed is better described by the appel-

lations of *hydrostatic bed* or *floating bed* than of *water bed.* Any water-tight sack gives a floating support if, when partially filled, it is placed in a sufficiently resisting hollow, such as may be formed in a mattress or paliasse, or otherwise.

805. Proving how new the idea of a bed giving hydrostatic support was to professional men as well as to others, I may mention that Sir Astley Cooper when calling upon me after visiting a sufferer lying on the bed, to converse about it, said he would like to lie down upon one then before him, but he feared that his great weight might burst it. The answer that he would no more burst it than a seventy-four bursts the sea made him smile but gave the information wanted, namely, that he would be supported not in any degree by the strength of the covering sheet but altogether by the buoyancy or upward pressure of the water—as he found immediately on lying down.

806. Some time after this, he sent to inquire whether the bed could be adapted to the case of a patient of his, an old gentleman who had broken his leg, but who was rendered almost frantic by the irksomeness and pressures of his fixed position on a common bed. The answer was that while the floating mattress would give relief in the respect referred to, its unstable nature might not favour the reunion of the broken bones. And

if the trough were made very small and narrow as here sketched, so that the body of the patient and the mattress under him resting on a half-filled sack of water below, would be held steady, there would not be room to give any help when wanted below his body. I therefore advised that the narrow trough here sketched should be made, but that instead of a wooden solid bottom there should be a set of loose straps with buckles at their ends hanging across the frame from side to side, which could be so adjusted as to form a hollow depression lined with a mattress so fitted to the shape of his body that the support would be nearly as soft as that of the floating mattress, and the patient would be held as steadily and securely as a kernel is in its shell. There would be also the advantage that by unbuckling one or two of the straps no need would ever arise to move him from his place.

807. This bed was made, and answered perfectly. Being returned to my apparatus room, after it had served its purpose, it was lent in other cases, and as a model for others to be

made like it. When in place of the cross-straps for a bottom to the trough, one breadth of canvas is used, and a large sack of caoutchouc cloth containing a few gallons of water is laid upon the canvas, that water floats a mattress and forms a complete hydrostatic bed for the heavy part of a patient's body on which bed sores usually form. The delay until now of the publication of an edition of the "Elements of Physics" subsequently to the fifth, has prevented the capabilities of these beds from being known so fully as it is hoped they will now become. The strap-bed or canvas-bottom bed above described, when the moveable flaps of the trough which support the pillows for the head and legs are taken off and applied as lid and bottom to the trough, as was done in the first specimen made, give it the appearance of a flat light portable portmanteau, although, in reality, a complete bed with its mattress and water-sack. It can scarcely be necessary to remark that a water-sack of the caoutchouc cloth large enough to fill the wooden trough of the common full-sized bed constitutes one form of the bed.

808. There are two remarks of importance to be made here. As a warm hand held very near a looking-glass in cold weather immediately dims the surface by the condensation upon it of the insensible perspiration, so if a patient on the water-bed have only one or two folds of blanket or a thin mattress between him and the sheet which lies on cool water, the insensible perspiration would traverse the blanket or mattress and settle on the sheet as dew. This is perfectly prevented by placing a thin sheet of the caoutchouc cloth above (not below) the mattress so as to prevent the vapour from coming into contact with the lower sheet. Many persons not understanding this case have erroneously suspected the water-sheet not to be water-tight. —The other remark is, that a person lying on the strangely soft water-bed does not require to be changing position as on harder beds, and he may consequently rest so long in one position that the unmoved joints acquire a degree of stiffness. Such effect is altogether avoided by purposely changing the position from time to time.

809. The preceding paragraphs are intended as much to direct in the choice and use of common beds for the sick, as to announce and describe the hydrostatic bed for the cases in which it may be required. At present the medical attendant generally leaves whatever regards the bed to the judgment of friends or nurses; but evidently, he who has been led to reflect how much

the course and event of a malady may depend on the patient's being supported, so that no pain shall arise from local pressure, and as little muscular weariness as possible from constrained position, will deem the bed-management worthy of his own serious attention, and will be able more judiciously both to choose and to use beds.

The author gave no exclusive right or privilege to any person to make this bed. There were many makers, but they were not all good makers. The author has been well satisfied with the performance of Messrs. Smith, of No. 253, Tottenham Court Road, who supply the beds to various hospitals. And he has the hope that Messrs. Weiss, surgical instrument makers, of No. 62, Strand, will supply them with the perfection of workmanship and care which characterize all the work executed in their establishment.

The SLACK-SIDED CUSHION.

810. Among the many forms in which soft uniform fluid pressure may be rendered useful as a remedy by persons understanding hydrostatics, there is another which will be fitly considered here, which I have called the *slack-sided cushion.*

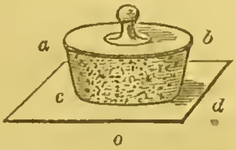
A finger pressed for a little while against the rosy cheek of a child, when lifted leaves behind a white mark, because the pressure had forced the blood out of the superficial vessels. Now, there are cases of unhealthy abundance of blood circulating in parts, and feeding morbid actions and growths in them, which the slack-sided cushion can with certainty control.

If a person push a hand into a mass of soft poultice contained in a bag of strong cloth, the neck of which bag is secured round the wrist by a ligature, he may then lay the covered hand on a table, and over the hand may let a weight be placed which would crush a naked hand,—and he will not feel pain. The explanation is, that, the pressure reaches the hand, converted by the poultice into a fluid pressure acting uniformly and softly all round, and equally in all directions—as the weight of the atmosphere constantly presses 15 pounds to the inch on the whole surface of living bodies without being felt. (See Art. 571.)

Now this kind of pressure can be made on any part of the body without the presence of any ligature, or restraining means like that which surrounds the wrist of the hand in the poultice-bag; and if it be made so strong as four pounds on the inch

which is the force of the heart's action injecting blood into all living parts, it will completely command the supply of blood to the part. The details of such applications belong to the professional Appendix.

Suppose *a b* to represent a round flat board forming a top or lid, to which a bag of conical shape is attached all round, the bag having an open mouth below at *o*, and its edges turned inwards there, as from the sides at *c* and *d*. If the bag be filled with poultice, and be placed on a flat surface with its mouth down, it is evident that no pressure on the top can force any of the contents out, because the turned-in edges act as valves, completely preventing escape. And, clearly, if a ball, an egg, or other body were placed on the table, so as to be within the mouth of the bag and in the poultice, it would bear, without harm, as fluid pressure the whole of any pressure made on the top of the bag. And if the bag, instead of being filled with poultice, had within it only a large bladder, or a bag of soft caoutchouc cloth half filled with air, and therefore lying in folds, the same results would follow.—A larger form of this modification, with the slack side uppermost, half filled with slack cushions containing air or water, forms the softest possible seat for invalids.



The Pulse.

811. The opinion which the ancients held that the arteries contained *vital spirits* or *air*, and not blood, rendered the pulse to them a very mysterious phenomenon; and many curious hypotheses were framed to explain it. We now know that each gush of blood thrown into the aorta from the great left chamber of the heart causes an undulation, perceptible to the touch, to spread from the heart to the most distant extremities.

812. It is a remark respecting the pulse, worthy of full consideration, that if the purpose of the heart and arteries were merely the propulsion and conveyance of the blood, their structure and action would form signal deviations from the ascertained rules of fitness in mechanics. In machines of human contrivance, it is one of the most important maxims "to avoid shocks, or jerking motions;" and in former parts of this work, we have described fly-wheels, air-vessels, springs, &c. as means of accomplishing this object, and thereby of preventing the wearing and straining of parts which else might happen. In the human

body, also, we have had to describe the admirable elasticity of the spine, of the arch of the foot, of the cartilages of joints, &c. as contrivances answering the same ends; and to remark that, in other cavities than the heart, which are alternately filled and emptied like it, as the stomach, bladder, uterus, &c., there is a smooth and gradual action. The heart alone is the rugged anomaly which, from before birth unto the dying moment, throbs unceasingly, and sends the bounding pulse of life to every part; and which moreover, instead of being secured and tied down to its place, is attached at the extremity of the aorta, like a weight at the end of an elastic branch of a tree, and every time that it fills the aorta, is thrown with violence, by the consequent sudden tendency of that vessel to become straighter, against the ribs, in the place where the hand applied, feels it so distinctly beating.

One use of the pulsation of the heart probably is, by the *agitation* and kind of *churning* which the blood suffers in passing through it, to keep in complete mixture all the heterogeneous parts of the blood, which so readily separate when left to repose:—but this cannot be the only use, for that one object might have been more simply attained; and we may conclude that the phenomenon has relation to some important law of life yet veiled from us. The cause commonly assigned for the heart's contraction is a peculiar stimulus of the blood; yet if we reflect that the heart will beat after removal from the body, and when it contains only air, and that during life it beats with extraordinary regularity, whether the state of the circulation allow it to empty itself at each beat or not, we perceive that the cause is more obscure. We cannot contemplate this subject without perceiving a strong analogy between the action of the heart and some electrical phenomena in which there are successive accumulations and exhaustions of power; and, recollecting the important relations which modern researches have shown to exist between electricity and certain other actions of life, the inquiry becomes very interesting. Galvanism can excite the muscles to their usual actions; it powerfully affects the secretions and the digestive function, and the breathing in asthma: strong animal passion seems to produce electrical excitement: and certain animals have the faculty of stunning their enemies by an electrical discharge. The pulse, then, in its sudden, strong, and regular recurrence, may be a kindred phenomenon.

Circulation in the Head.

813. The head may be considered as an air-tight vessel or cavity of bone, containing chiefly brain and blood, and having openings occupied by blood-vessels leading to and from the heart. The atmospheric pressure, therefore, always keeps the head full, as it keeps the top of a syphon full; and because the substance of the brain itself does not, more than water, sensibly change in bulk by any ordinary degree of pressure, there must always be very nearly the same quantity of blood in the head, how much soever the quantity may vary in the body generally. Regard to this important truth, a knowledge of which has followed the discovery of the true nature of atmospheric pressure, enables us to explain many hitherto obscure facts, both in health and in disease, as will be seen in the medical appendix.

If from any cause the arteries in the head become too full of blood, in the same proportion the veins must become too empty; or, if the veins be too full, the arteries must be too empty; and in either case the circulation in the head will be in a corresponding degree impeded, because when one part of a channel is much narrowed or diminished, the current throughout the whole is slackened. Now as insensibility supervenes when the supply of fresh blood to the brain is interrupted, and death follows if the interruption continue long, it seems evident that in many of the cases of apoplexy, where, on inspection, there is found nothing but a fulness of the arterial or of the venous system of the head, death has happened merely because the circulation was arrested in this way. In other parts of the body, not circumstanced like the brain, an excess of blood in one set of vessels may happen without inducing deficiency in another, and therefore with perfect impunity to the individual.

Simple increase of pressure produced by the blood on the brain, provided the proper balance exist between the quantity in veins and arteries, has no injurious effect. This is proved by the safe descent of a person in the diving-bell, where at thirty-four feet under the surface of the water the body is bearing an additional pressure of fifteen pounds on the square inch (see page 212), which pressure through the blood-vessels affects the brain as much as any other part.—On the other hand, when a man climbs a mountain, or is lifted in a balloon, the brain is less pressed than usual; but the proper balance in artery and vein

being maintained, no inconvenience is felt. The inhabitants of some of the valleys among the Andes are as far above the sea as they would be at the top of Mont Blanc, where the atmosphere presses only half as much as on the sea-shore, but they enjoy good health.

814. There is a fact very simple and very important which deserves mention here. Sudden death occurs frequently during surgical operations above the heart-level, when a vein is accidentally cut into, and a little air is heard to whistle in, and so to reach the heart. It was long supposed that the heart had the power of sucking air in when such an aperture was made. This is error, but the fact is, that a vein descending from the head of a sitting person is as the descending leg of a syphon, and if it be wounded the air enters immediately. Such a fatal accident cannot happen where the person operated on is in a lying posture.

815. Water in the head is said to kill by fatal pressure on the tender brain: but, in reality, it kills by keeping out the blood, and so mechanically arresting the circulation. Accordingly, we see, that where the *fontanelle* still remains open, or where the *sutures* or joinings of the skull will yield, water may accumulate to a great degree without causing much disturbance.

A tumour in the brain, which would be of no consequence if the brain were unconfined, soon becomes fatal by occupying room in the skull, and to the extent of its size excluding or checking the supply of blood.

If the substance of the brain at all increase and diminish in bulk, as muscles, &c., under certain circumstances, do, in the body below, all such changes must produce a considerable effect on the cerebral circulation and functions.

RESPIRATION OR BREATHING.

The chest is a cavity which alternately expands and contracts like a pair of bellows, thereby taking in and again expelling a certain volume of atmospheric air. This air comes nearly into contact with every particle of the circulating blood as that passes at every revolution through the spongy lobes of the lungs occupying the chest. These lobes consist chiefly of delicate air-cells and minute capillaries, so thin that air can act through their substance. Great changes are produced in the blood by the manner of contact described, and the animal warmth is one of the effects.

816. As the motion of a windmill depends altogether on the

breeze to which its vanes are exposed, so does the motion and the life of that complex structure, the animal body, depend on the supply of fresh air for its breathing. If this supply be withheld but for a few moments, painful convulsions ensue; and if for a still longer period, the body, however perfect and beautiful, is made a lifeless corpse, soon to putrefy and be decomposed.

The mechanical nature of air, as to its lightness, elasticity, &c., and the fact of its forming an ocean around the earth of about fifty miles high, are now well understood, and have been fully explained under *Pneumatics;* but the precise nature of its life-sustaining action has yet to be elucidated by additional research of chemists and physiologists. Thus far, however, we know—that the ingredient called *oxygen,* constituting a fifth of the atmosphere, is the most essential part,—which air, by being breathed once, is rendered unfit for further respiration at the time—and that a man requires the oxygen of about a gallon of fresh air per minute. The enterprising Mr. Spalding, who introduced the use of the diving-bell, descended for the last time with a companion on the coast of Ireland. Owing to the signal cord becoming entangled round the great rope supporting the bell, which had turned in descending, he could not make known above their want of air, and both were found dead when the bell was drawn up soon after, although the water had not touched them.

We know generally of the life-supporting action of air, that it consists in some change operated by the air on the blood, during which some thing or things are given to it, and some thing or things are taken away; and we know that the function of respiration has merely to bring air and blood together in the cavity of the chest, that this change may take place. The blood while in the chest is moving along a part of its course, in vessels of extreme minuteness and thinness, and the air at each inspiration rushes in among these, so that every globule of blood passes within its influence. And the blood, which, after having served the purposes of the body, arrives at this part of its course dark and impure, immediately after its exposure to the air, enters the left chamber of the heart, of a bright scarlet colour, and thence departs to carry new life to the general system.

817. The force of a healthy chest's action in blowing is equal, as stated in last section, to about *one pound* on the inch of its surface; that is to say, the chest can condense its contained air

with that force, and can therefore blow through a tube the mouth of which is two feet under the surface of water. In the opposite action of sucking or drawing in air, the power is nearly the same.—In both actions, however, it is possible to use the cavity of the mouth separately from that of the chest; and the mouth being smaller, with stronger muscles about it in proportion to its size, it can act more strongly. Some men can suck with the mouth so as to make nearly a perfect vacuum, or to lift water nearly thirty feet. And a expert operator with the blow-pipe can keep up an uninterrupted blast by shutting the mouth behind, while he inhales, and replenishing it as is required in the intervals.

In *coughing*, the *glottis* or top of the windpipe, by a curious sympathy of parts, is first closed for an instant, during which the chest is compressing and condensing its contained air, and on the glottis being then opened, a slight explosion, as it were, of the compressed air takes place, and blows out any irritating matter that may be in the air-passages—nearly, only with inferior force, as the burst from the chamber of an air-gun discharges its bullet.—This shutting of the glottis to allow the compression of the air, and the subsequent opening to allow the discharge, may recur at very minute intervals, and many times for one fill of the chest,—as instanced in whooping-cough.

Sneezing is a phenomenon resembling cough, only the chest empties itself at one throe, and chiefly through the nose, instead of through the mouth, as in coughing. The irritation that produces sneezing is generally in the lining membrane of the nose.

Laughing consists of quickly repeated expulsions of air from the chest, the glottis being at the time in the condition to produce voice; but there is not between the gusts, as in coughing, complete closure of the glottis.

Crying differs from laughing almost solely in the circumstance of the intervals between the gusts of air being longer. Children laugh and cry in the same breath, and it is often difficult to mark the moment of change.

Hiccup is the sudden stopping, by a closure of the glottis, of a strong inspiration nearly at its commencement.

818. When a man *strains* to lift weights, or to make any powerful effort, the air is shut up for the moment in the chest, that there may then be steadiness and firmness of the general person. At such a time, by the compression and condensation

of air around the heart and large blood-vessels, the blood is determined violently outwards from the chest, and often rises to the head, with force that produces giddiness, or even apoplexy,—and the eye will sometimes become suddenly bloodshot, from a small vessel giving way; and leech-bites will break out afresh.—The force of this pressure outwards is measured, as already stated, by a column of about two feet of blood; and this is therefore the measure of the additional arterial tension in the body generally.

819. *Suffocation* is the name given to what happens when the supply of air to the lungs is in any way prevented. The blood, not then refreshed by the approach of the air, rises to the brain unfit for its purpose, and confusion of thought is immediately produced, soon followed by convulsion and death.

820. In *drowning*, communication with the atmosphere is cut off altogether by the supernatant water. If during submersion the chest expands, it can receive water only instead of air. The nerves and muscles, however, at the entrance of the windpipe, are so irritable, as to be immediately excited by the contact of any unusual matter, and for a considerable time they keep the passage shut against the liquid seeking entrance. It is partly on this account that the body of a person, after submersion in water and apparent death, may often, if recovered within a moderate time, be restored to life.

The administration of chloroform, and of medicated airs generally, will be described in the Medical Appendix.

THE VOICE AND SPEECH.

The air which enters the chest as breath, while re-issuing through the glottis is caused, at the will of the person, to produce sound. This, modified by changed action of the parts in and about the mouth, becomes distinct articulations or words, giving to man the faculty of speech, through which the noble faculties of his mind manifest themselves and operate.

The chest, the air-passages, and mouth, constitute the organs of voice and speech.

821. An inquirer into the constitution of the world around, meets with few things more to be admired than that faculty in the human mind by which it can associate the ideas of objects and phenomena with any signs chosen at will, so closely that the ideas are afterwards excitable by the signs almost as vividly as by

the objects themselves. The inhabitants of China, for instance, having devised thousands of grotesque written characters, and determined what object each of these should recall, when by study they became familiar with them, may have the bodily eye poring over pages of the crooked scratches, while the mental eye, through them is viewing any part of the most pleasing imagery of nature: and the characters may be rendered intelligible even to persons deaf and dumb as well as to those who speak; and they serve as media of thought and communication through many provinces and countries of which the spoken languages have no common resemblance.

But if the ready remembrance of *visible* signs be wonderful, which have a permanent existence, and some of which may have resemblance in form to the things signified, how much more marvellous is it that an *audible* sign, that is, a passing sound or fugitive breath, called a word, should serve as well; and that by a succession of mere sounds, having so little natural connexion with the things signified, that they are totally different in different countries, and are changing with fashion from age to age, any train of thought may be made to pass through the minds of auditors, so as to excite and to leave impressions almost as vivid as from realities! Such is the fact, and it is in great part owing to this, and to a corresponding faculty of producing at will a sufficient number of distinguishable sounds, that man owes his elevation above the brutes of the field. His noble powers of intellect would have lain dormant and unknown, had he wanted the faculty of comparing his invisible thoughts with those of his fellow-men, and of arranging and recording many of them by means of signs.—Written language is a double remove from the objects themselves, being *visible signs* not of things, but of the *audible signs* of things.

The curious apparatus by which man is enabled to produce a sufficient variety of sounds to answer his purposes, passes generally under the denomination of *the organs of speech;* because the act of using sounds which have meanings assigned to them is called speech. It consists of the chest for containing air, and forcing it out along the windpipe to the larynx or cartilaginous box in the throat, where the narrow aperture of the glottis produces the voice and varies its pitch; and of the short passage of the mouth, with the tongue and lips, for varying the dimensions of that.

In the chapter on Acoustics we explained that sound is the

effect produced upon the ear by certain tremors or undulations conveyed to it generally through the medium of the air; and we explained how air, forced out from the human chest through the opening at the top of the windpipe, causes the elastic lips of that opening to vibrate, and to excite audible tremblings. We have now to show that this sound, in passing forward from the top of the windpipe, can be modified at the will of the individual, in a great variety of ways—a variety, however, which is still simple.

The modifications of voice easily made, and easily distinguishable by the ear, and therefore fit elements of language, are about fifty in number; but few languages use more than about half of them. They are divisible into two very distinct and nearly equal classes, called, for reasons now to be explained, *vowels* and *consonants*.

822. Vowels, or the first class, are the simple voice issuing from the glottis through the open mouth, and influenced only by the degrees in which the mouth is more or less widened and elongated. They may be continued as long as there is breath to issue from the chest, and it is for this reason that they are named *vowels*, or *calling sounds* (from *voco*, 'to call'). The Roman letters, A, E, I, O, U, as generally pronounced on the continent of Europe, and as they are thought to have been pronounced by the Romans themselves of old, indicate the most easily distinguishable vowels. They are heard in the English pronunciation of the following syllables and words:—

The Roman letters	A	E	I	O	U
Syllables . . .	ah	eh	eeh	oh	uh
Words	are	they	Lima	more	rude
Or	bar	bear	beer	bore	boor
The short vowels corresponding	{ pat	pet	pit	pot	but

The order of position of the chief vowels exhibited here, is that of the Roman alphabet, but as the tube of the mouth may be compared with the tube of a flute, the sounds from which are sharp or grave according to the length allowed to act, the order I, E, A, O, U, more conveniently shows the natural relation of the sounds as they change by steps from that of the letter

I, produced by the narrowest and shortest condition of the mouth-passage to that of U, produced by the most elongated condition. The reader may try as follows:—

If a person begin sound by a simple noise or hum, such as remains after pronouncing the letter M, and if he then simply open the mouth wide, he produces the sound expressed by the letter A placed in the middle of the arrangement last given, and heard in the English word *are.*

If he then *narrow* the passage of the mouth a little, by raising the middle of the tongue towards the palate, and at the same time shorten it a little by slightly drawing back the lips, he pronounces the sound E of the table, as heard in the word *they.*

If he then still farther *narrow* the mouth by raising the tongue higher, and shorten it by drawing the lips farther back, the sound I is heard, as in the name *Lima.*

Going back then to the middle position and size of the mouth for the letter A, if, instead of narrowing and shortening as for E and I, he widen it a little by depressing the body of the tongue, and lengthen it a little by advancing and rounding the lips, the sound O is produced, as heard in the word *bore.*

If he then lengthen still more in the same direction, and narrow the outlet, he pronounces the sound U, as heard in the words *rude,* or *food.*

Intermediate degrees of narrowing and shortening, or widening and elongating, give intermediate vowels. The most important of these used in English are the slender E, which comes between E and I, heard in the second syllable of such words as *bended, tended,*—and that sound between A and O, heard in such English words as *awe, all, fall,* &c.

The possible number of vowels, however, is as great as the possible degrees in which the dimensions of the mouth may be altered. About twenty of them are sufficiently distinguishable, but few languages comprehend more than twelve. Modern art can produce the vowel sounds mechanically by means of tubes susceptible of changes of dimension in width and length.

The alphabets of Europe are very faulty in not all using the same characters for the same sounds, and in not having, according to the true intent of an alphabet, a character for each distinct sound. In English one letter is used for several sounds, as A in *water, far, fat, fate,* where it indicates four sounds perfectly distinct. In repeating the English alphabet, the A is pronounced

as the broad E of the Italians, and of continental Europe, the E as the I: the I (in *tide*, for instance), as the diphthong AI of more correct alphabets; and the U (in *muse*), as the diphthong IU. In consequence of the changes which the English have made in the meaning of the Roman letters, they now experience increased difficulty in learning modern continental languages; and their own pronunciation of the ancient languages, to all but themselves, is ludicrous, and almost unintelligible. The same cause renders the pronunciation of English difficult to foreigners, and thus restricts much, in other countries, the cultivation of English literature.

823. CONSONANTS.—To explain the second class of the modifications of sound so called, we may remark, that while any continued or vowel sound is passing through the mouth, if it be interrupted, whether by a complete closure of the mouth, or only by an approximation of parts, the effect on the ear of a listener is very striking, and is so exceedingly different, according to the *situation* in the mouth where the interruption occurs, and to the *manner* in which it occurs, that many very distinct modifications thence arise. Thus any continued sound as A, if arrested by a closure of the mouth at the external confine or lips, is heard to terminate with the modification which we choose to express by the letter P, that is, the syllable AP has been pronounced; but if, under similar circumstances, the closure be made in the middle of the mouth by the tip of the tongue rising against the roof, the sound expressed by T is produced, and the syllable AT is heard; and if the closure be made towards the back of the mouth by the tongue rising against the palate, we hear clearly the modification expressed by the letter K, and the syllable AK has been pronounced; and so of others. It is to be remarked, also, that the ear is equally sensible of the peculiarities whether the closure precedes the continued sound or follows it: that is to say, whether the syllables pronounced are as above, AP, AT, AK, or, on the contrary, PA, TA, KA.—The modifications of which we are now speaking, appear then not so much to be sounds, as distinguishable manners of beginning and ending sounds; and it is because they are thus only perceivable in connexion with vocal sounds that they are called *consonants*.

Now in the mouth, considered as a vocal tube, there are three situations, in which interruption of voice or breath may

most conveniently be made, and there are six modes of making it at each; so that eighteen distinct interruptive modifications or consonants hence arise. These we shall now describe.

824. The three great *oral positions*, as they may be called, are represented in the following outline, which may be considered as exhibiting the tube of the mouth, with the letters so placed as to show in what situations in the mouth the sounds represented by them are severally produced.

825. *Table of Articulations.*

	Mute.	Semimute.	Semivowel or nasal.	Aspirate.	Vocal Aspirate.	Vibratory.	
LIPS	P	B	M	F	V	*pr*	LABIAL.
TEETH	.	.	.	th	th	.	Dental.
PALATE.	T	D	N	S	Z	R	PALATAL.
	.	L	.	sh	J	.	with the edges of the tongue depressed.
THROAT	K	G	ng *n*	*ch* H	*gh*	*ghr*	GUTTURAL.

1st. At the external confine of the mouth, or lips, giving the *labial* articulations, of which P is an example.

2nd. In the middle of the mouth, where the tip of the tongue approaches the palate behind the teeth, producing the *palatal* articulations, of which T is an example.

3rd. Near the back of the mouth, where the body of the tongue approaches the palate, giving the *guttural* articulations, of which K is an example.

826. And the *six modes* in which the voice or breath may be affected in passing through each of the three positions of the mouth, are,

1st. A sudden and complete stoppage, producing what may be called a *mute* articulation: *viz.* P, in the labial position;

T, in the palatal; and K, in the guttural. A mute may also be made by stopping the breath exactly at the teeth, *viz.* a *dental mute;* but it is hardly distinguishable from the *palatal mute*, produced just behind it, and being less perfect, is not used.—Some awkward speakers substituting it for the proper mute, are said to *speak thick.*

2nd. A sudden shutting, as in the last case, but the voice being allowed to continue until the part of the mouth behind the closure be distended with air.—This produces the *semi-mutes,* B, D, and G (as heard in the syllables AB, AD, AG), for the three positions. If the sides of the tongue be depressed after it has taken the position required for T or D, the sound L is produced; and the letter is, in the table, placed below D, although the sound, from being continuable, is not in any sense a *mute.*

3rd. The positions closed as for the mutes, while sound is allowed to pass by the nose.—Thus arise the *semi-vowels* or *nasals,* M, N, NG, for the three positions.—NG (as in *king*) is a simple sound, although our imperfect alphabet has no single letter for it. The nasal sound of the French language, which gives it so great a peculiarity, approximates to the English NG, but differs from it in the sound being allowed to pass by the mouth, as well as by the nose. It is pointed at by the small *n* in the table, and like the other sounds which do not occur in the English language, is here printed in the Italic character.

4th. Breath only (or whisper) allowed to pass at the three oral positions nearly closed.—Hence come the sounds which we call *aspirates, viz.* F, for the labial position, TH and S, for the palatal, and CH (heard in the Scottish word *loch*), for the guttural; the TH and CH are simple sounds, although each expressed in Britain by two letters. The TH is heard in the word *bath,* and is the sound expressed by the single letter ϑ of the Greeks. The CH is heard in the German, *ich,* and is the χ of the Greeks. The *soft aspirate* TH, is more easily made by pressing the tongue gently against the teeth, and allowing the breath to pass all around, than by the true palatal approximation of parts, and the *soft dental aspirate,* therefore, is used in preference to the *palatal.* The letter S is the *hard palatal aspirate,* and differs from the *soft palatal aspirate* TH, in the breath being made to issue with greater force and over a moist or wet surface, and only by a narrow space over the centre of a

rigid tongue, instead of on all sides of a soft tongue, as for TH. French people, on first attempting to pronounce TH, substitute for it the D, or the S, or the Z (which is nearly related to S, as explained below). The author has found it easy to enable them to pronounce the TH at once, and perfectly, by explaining its nature as above. If we raise the sides and lower the tip of the tongue while pronouncing S, we produce the simple sound expressed by the English double letter SH; as, by depressing the sides of the tongue while making D, we produce L.

5th. Using *voice* in the same manner as *breath* or *whisper* is used for the aspirates.—This produces the sounds called *vocal aspirates, viz.* V, TH, Z, J, and GH. TH, *vocal aspirate,* is heard in *bathe,* as contrasted with the *simple aspirate* in *bath;* Z comes from the S position, only with *sound* instead of *breath;* SH pronounced with *voice,* becomes the J of the French in the word *je,* or the sound heard in the middle of the English word *vision.* GH is a simple guttural aspirate sound used in German, but not in English.

6th. Shaking the approaching parts in the three positions.—We thus make *vibratory sounds,* of which the middle position gives the common R, the only one of them used in England. Some faulty speakers of English, however, make the *labial vibratory* by shaking the P in such words as *property;* and many use the *guttural,* which is the *burr* of Northumberland, and the common affectation in Parisian speech, termed *parler gras,* or *grasseyer.*

827. *Additional Remarks.*

The sound of H is an *aspirate* produced even behind the situation of the *guttural aspirate ch:* it is, indeed, merely a forcible passing of the breath through the very back part of the mouth or throat.

CH, in such words as *chain,* means T before *sh.*

J, as heard in the English name *John,* is a compound sound, *viz.* D before the simple J of the table, which is the S of *vision.*

LL. The liquid or double LL of the French, as heard in the word *paille,* is merely L with the letter Y begun to be pronounced after it. It is heard in the English words *billiard* and *halyard,* and would be their terminating liquid were the syllable *ard* not pronounced. The double LL of the Welsh, as in the name

Lloyd, has the first L pronounced as an *aspirate*, that is, as a whisper, and the second in the ordinary way.

GN. The soft GN of the Italians and French, is the English N with Y begun to be pronounced after it. It is heard in our word *tanyard;* and in the Italian words *pegno*, *bagno ;* and in the French word *craignent.*

C, in English, stands always either for S or K, as in the words *certain* and *car*, and has no sound proper to itself.

Q, in English, expresses the sound of the letter K, with U following it; and yet, uselessly, U is always written after Q.

X, in English, means either KS, as in the word *axle*, or GZ, as in the word *example.*

The consonants are best heard by sounding them with voice before them: that is to say, by making them rather terminate a syllable than begin it; pronouncing B, D, G thus, *eb*, *ed*, *eg*, rather than their common alphabetical names *be*, *de*, *ge*.

The labial sounds may be made either by the two lips, or by one lip and the opposite teeth. F may be pronounced, for instance, by the lips only, or by the lips and teeth; and some persons awkwardly make it by the under teeth and upper lip.

The letters Y and I, in most modern languages, stand for nearly the same sound. In English, for instance, *bullion* and *minion*, might be written *bullyon* and *minyon*, without suggesting a change of pronunciation. In the words *yard*, *you*, *yes*, &c. the Y is a short I, very closely joined to the following sound.—W is also thus a short U, as perceived in the words *war*, *we*, &c.

The author believes the analysis of articulations to be the best basis for a system of short-hand written characters. He has tried such a system, and has found it exceedingly convenient.

Lisping is chiefly the habitual substitution of the aspirate TH for the S and SH.

Whispering is articulation without voice; that is to say, articulation while breath only is passing.

828. *STUTTERING*, *stammering*, *hesitation of speech*, are terms implying an interrupted articulation, accompanied generally with more or less of straining and distortion of feature. It is remarkable with respect to this defect, that when the present work was first published, scientific or regular medicine had taught as yet no probable means of relief for it, although the frequent success of non-professional, and often ignorant individuals, by a mode of treatment which they solemnly bound their

patients not to divulge, proved the cure, to a certain extent, to be both possible and not difficult.—The author's attention had been drawn to the subject some years before, by a very interesting case known to him, of stuttering connected with other disease; and it was in analyzing the subject with a view to the treatment of that case, that he framed the analysis of articulation contained in the preceding pages, and drew up some of the additional observations which are now to follow. A cure was obtained; but as the case possessed a favourable peculiarity in the powerful mind of the individual, to which the author attributed much, and as he had not leisure from his ordinary professional duties to pursue the subject, or to ascertain in what respects his plan might differ from that employed by the most successful of the practitioners who concealed their proceedings, he gave his remarks in former editions of this work, merely as continued elucidation of the subject of speech. He is now, however, enabled to state, that the analysis here made has enabled other sufferers to know the nature of the morbid affection, and to adopt effectual means of relief. As regards children, any intelligent instructor of youth who chooses to study the subject, may quickly remove difficulties, and correct defects.

Command over the organs of speech is acquired in the same way as over all the other muscular organs of the body; those, for instance, used in walking, skating, fencing, performing on musical instruments, &c.: that is to say, at first, a distinct act of volition is required for every individual movement; but the law of association or habit rendering the actions easier with each successive repetition, they are at last formed into connected tribes or trains, which appear as obedient to a single wish as the separate elements originally were. A child at first exerts as distinct and powerful a volition to pronounce the syllable *pa*, as after some practice to double the syllable and make *papa;* or after still more practice, to pronounce the longest and hardest word of the language:—nay, at last, where there is strong and healthy power of association, complete sentences, and even rounded periods of eloquence, are poured out like single words, the mind of the speaker seeming at liberty, after each sentence or period is begun, to continue it while meditating and preparing that which is to follow. As the faculties of locomotion and of speech are acquired in infancy and early childhood, persons no more recollect how they gradually acquired them, than how their limbs grew; but the progress described above may be watched by any individual of mature years in his own person.

while he is learning such an art as that of playing on a musical instrument. He will find, that at first every finger which is moved to produce a note obeys a distinct thought and volition; that soon, short trains of connected notes become obedient to the will almost like a single note; that then, by degrees, longer and longer trains or passages become familiar, until at last the instrument is as obedient to the practised player, as voice is to the singer, or speech to the orator.

There is great original diversity among individuals as to their powers of muscular association, and therefore, also, as to their aptitude for acquiring the various faculties of which we have been speaking. Thus some children walk well before a year, others require a much longer time, and some never succeed perfectly until they have had lessons from the dancing-master or drill serjeant.—So, again, many people, by ear and imitation alone, learn easily to play on musical instruments; but others must begin by studying the written notes, and the precise *fingering* by which each note is produced on the instrument; and many, unless the notes be constantly before them, cannot play at all.—So again, all persons may be said to learn to speak at first by ear and imitation; but many grow up to a certain age with defects, which judicious lessons from parents or other tutors are required to remove; and there are some, as stutterers, who, owing to a naturally weak or irregular association, or to some accident in early life, which has strongly affected their nervous system, retain defects which no ordinary teaching can correct. It appears, then, that an analysis and scale of articulate sounds, with minute description of the organic actions required to produce them, like the scale which we possess for music, in the *gamut* and rules for fingering, should give nearly the same assistance to the speaker, which the gamut gives to the player. The table and analysis contained in the preceding pages is intended to supply this information. It is constructed from minute consideration of the organs of speech while in action. It agrees in many respects with the common grammatical divisions of elementary sounds, but in others it pursues the analysis in a different way, and considerably farther. A person who understands it well, will have, while he speaks, an intelligent perception of what he is doing, in addition to the parrot-like faculty of habit, or of repeating by rote, and will thus command any desired sound by two powers instead of one. And, as a musician, when his musical memory fails him, finds help by

thinking of his written notes and their relation to his instrument, so may a stutterer, when hesitating at any sound, receive benefit by thinking of the letter which represents it, and of the position of the organs required for that letter. Then by frequent practice in making the particular combinations of sound which are difficult to him, he may strengthen the useful habit, and ultimately overcome his defect.

The most common case of stuttering, however, is not, as has been almost universally believed, where the individual has a difficulty in respect to some particular letter or articulation, by the disobedience of the parts of the mouth which should form it, to the will or power of association, but where the spasmodic interruption occurs altogether behind or beyond the mouth, *viz.* in the glottis, so as to affect all the articulations equally. To a person ignorant of anatomy, and therefore knowing not what or where the glottis is, it may be sufficient explanation to say, that it is the slit or narrow opening at the top of the windpipe, by which the air passes to and from the lungs, being situated just behind the root of the tongue. It is that which is felt to close suddenly in hiccup, arresting the ingress of air, and that which closes, to prevent the egress of air from the chest of a person lifting a heavy weight or making any straining exertion; it is that also, by the repeated shutting of which a person divides the sound in pronouncing several times, in distinct and rapid succession, any vowel, as o, o, o, o. Now the glottis during common speech needs never be closed, and an ordinary stutterer is often cured, if, by having his attention properly directed to it, he can keep it open. Had the edges or thin lips of the glottis been visible, like the external lips of the mouth, the nature of stuttering would not so long have remained a mystery, and the effort necessary to the cure would have been suggested to the most careless observer: but because they were hidden, and professional men had not detected in how far they were concerned, and the patient himself had only a vague feeling of some difficulty, which, after straining, grimace, gesticulation, and sometimes almost general convulsion of the body, gave way, the uncertainty with respect to the subject has remained. Even many persons who by attention and much labour had overcome the defect in themselves, as Demosthenes did, have not been able to describe to others the nature of their efforts, so as to insure imitation: and evidently the quacks who have succeeded in relieving many cases, but in many also have failed, or have

given only temporary relief, have not really understood what precise end in the action of the organs their imperfect directions were accomplishing.

Now a common stutterer, understanding of anatomy only what is stated above, will comprehend what he is to aim at, by being farther told, that when any continued sound is issuing from his mouth, as when he is humming a single note or a tune, the glottis is necessarily open, and therefore, that when he chooses to begin pronouncing or droning what we have already described to be the simplest of vocal sounds, namely, the indistinct vowel *e* (to do which at once no stutterer has any difficulty), he thereby opens the glottis, and renders the pronunciation of any other sound easy :—or if, when speaking or reading, he joins his words together, nearly as a person joins them in singing (and this may be done without its being at all noted as a peculiarity of speech, for many persons do it in their ordinary conversation), the voice never stops, the glottis never closes, and there is of course no stutter. The author has given merely this explanation or lesson, with examples, to persons who before would have required half an hour to read a page, but who immediately afterwards read it smoothly; and who then, on transferring the lesson to the speech, by continued practice and attention, obtained the same facility with respect to it. There are many persons not accounted peculiar in their speech, who in seeking words to express themselves, or while coming to a decision, often rest between their words on the simple sound of *e* mentioned above, saying, for instance, hesitatingly, "e..... I e..... think e..... I shall,"—the sound never eeasing until the end of the sentence, however long it may be delayed. Now a stutterer, who, to open his glottis at the beginning of a phrase, or in the middle after any interruption, uses such a sound, would not even at first be more remarkable than a drawling speaker, and he would only require to drawl for a little while, until practice facilitated his command of the other sounds. Although producing the simple sound mentioned is a means of opening the glottis, which by stutterers is found very generally to answer, there are cases in which other such means may be more suitable, as the intelligent preceptor will soon discover.

While the spasmodic closure of the glottis, as above described, is the common cause of stuttering, there are also cases in which the cause is a spasmodic prolongation of some of the aspirates or semi-vowel sounds, as of *s*, *m*, *l*, &c. Fortunately,

however, the substitution of the simple sound gives relief equally for all.

While the relief of many stutterers has been accomplished by their own efforts, after the study of what was written in the first edition of this work, the following additional rules or forms of direction were found useful to others; and a commentary upon them making them perfectly intelligible, would seem to comprehend much of what can be thus communicated upon the subject.—1. Familiarise yourself with the idea of a *continued sound*, as of the roar of the sea or waterfall, or the note of an organ-pipe, and feel that your speech is to be as uninterrupted.—2. Then never hesitate again at a particular sound, but substitute always the simple continued sound for any threatened defect, and rest upon it until power be felt to overcome the difficulty.—3. Never repeat words or syllables.—4. The simple sound must become the first syllable (*closely* joined) of every difficult word, until the morbid habit be weakened. The object of all these directions is to enable the patient, first, to substitute universally the soft *drawl* for the *stutter*, and then, as soon as possible, to discard the *drawl* too.

The view given above of the nature of stuttering and its relief, explains the following facts, which to many persons have appeared very extraordinary.—Stutterers often can sing well, and without the least interruption; for the tune being continued, the glottis does not close.—Many stutterers also can read poetry well, or any declamatory composition, in which the uninterrupted tone is almost as remarkable as in singing.—A person who draws in a deep breath before beginning to speak, as he cannot long retain the air, and the glottis must be open to let it escape, is to a degree secured against the occurrence of stuttering. The secret remedy of a foreign quack, who years ago got much money from Englishmen, was the direction thus to fill the chest before beginning to speak.—The cause of stuttering being a weak and easily disturbed association of certain muscular actions, we have the reason why any degree of anxiety or dread as to speaking well, exceedingly increases the defect; and why many stutterers, who cannot make themselves intelligible in society, still, when alone, can speak and read as perfectly as any other person. This explains also why many stutterers, who have gone to live for a time at the houses of pretended curers of their defect, have felt themselves singularly relieved from the moment of entering the house; because,

knowing that they were expected to speak ill, they had no fear of disagreeably attracting attention, and therefore had their powers much more at command. These persons, on returning to the world, have generally stuttered as badly as ever, but many of the asserted cures of stuttering, with certificates obtained from the parties at the time, have been of the nature now described.

829. The study of the table of articulations leads to the immediate correction of many minor defects in utterance, and is calculated to facilitate the acquirement of foreign languages. A lisping person, for instance, is cured at once, by being told that the tongue must not touch the teeth in pronouncing the letter S; and a Frenchman who deems it impossible for him to pronounce the English sound of TH, discovers that he cannot avoid doing so if he rests his tongue softly against his teeth, opened a little, and then forces breath or sound to pass between the tongue and teeth.

Several of the modern languages of Europe consist of nearly the same elementary or radical words, and differ among themselves chiefly by the prevalence in each of certain terminations, and of one or other of the related and convertible sounds classified in the analysis given above. A student, therefore, who, by analytical investigation, or considerable practice, has become impressed with the peculiar genius of a language, may invent, or determine by analogy, even before minute study, the majority of those words belonging to each which have sprung from a common origin. This remark is so true with respect to the languages of Italy, Spain, Portugal, and even France, that to persons familiar with them, they are at last listened to rather as the same language spoken by different individuals, than as languages in themselves different.

No intelligent mind can meditate on human speech, and its influence in the world, without being roused to vivid admiration. But for speech, the most gifted individuals who have lived, had they existed at all, could have been little superior in their worldly state to the inferior animals. As regarded the rest of mankind, Homer and Newton would have been born in vain.

THE DIGESTION.

Conversion of the Food into New Blood.—*The food on entering the mouth is broken down and soon half liquefied by mixture with saliva, gastric juice, &c., in the intestinal canal lower down. As it then*

passes along, what of it is fit to become blood is absorbed by the lacteal vessels, and carried by them to mingle with the blood returning in the great veins towards the heart.

The doctrines of fluidity, illustrating and illustrated by certain phenomena of digestion.

830. The animal body may be seen at first, in the maternal ovary, as a single speck of mucus; but from possessing life—wonderful life—the little nucleus, placed in new circumstances, begins to gather to itself substance from around, and it increases in bulk. For a certain time it remains attached to the body of its parent, and draws the material of its increase from its parent's blood; but after that time it is alone and entirely dependent on its own resources. Then we see brought into play that extraordinary apparatus now to be described under the name of the *digestive* or *assimilating organs;* which, under the direction of a nervous energy, can, out of almost any kinds of dead animal or vegetable matter, build up the beautiful living body to perfect maturity of size, and form, and faculty. And it is not only while their bodies are growing that animals require to take in and assimilate new matter, but also after maturity, in order to repair the waste of constant action. Supply of fuel and water to the steam-engine is not more necessary than of aliment to the living body.

Some of the less perfect animals take in sustenance almost like vegetables, by absorbent tubes that open on their surface; but by far the greater part receive it first into an interior cavity, where it undergoes certain preparation, producing liquefaction, and is then offered to internal absorbents, which drink up what can be useful, and carry it into the circulating blood. This internal cavity is called *a stomach.* Its form and appendages differ exceedingly in different animals, according to the nature of the substances which serve for their sustenance, and to various other circumstances.

In man, the process of digestion has the following steps. The food is first received by the *mouth.* It is there broken or torn into small portions by the cutting and grinding wedges, called *teeth,* with which the *jaws* are armed; at the same time a fluid called *saliva* is mixed with it, poured out from glands around, so as to reduce it into a pulpy mass: this mass is then pushed backwards by the *tongue* to enter the long tube called the *gullet* or *œsophagus,* which, by successive contraction of circular fibres,

propels it down to the pouch of the *stomach,* placed under the edge of the left ribs. From the internal surface of the stomach a liquor oozes, called the *gastric juice,* the most general solvent in nature, and which, attacking the received food, soon reduces it, of whatever kind, to the state of a pultaceous mass, named *chyme;* in this state it enters the narrow *intestinal* canal continued from the stomach, where it almost immediately receives a mixture of bile and pancreatic juice poured out from the liver and pancreas. After this mixture, as it gradually passes on, a chemical decomposition and separation of parts takes place, and the pure nutriment of the body assumes the state of a milky fluid floating among refuse. This milky fluid, called *chyle,* is taken up all along the canal by the numberless absorbent mouths of the vessels called *lacteals,* and is then carried to the *thoracic duct,* and by it into the blood near the heart, to supply the waste. The intestinal canal is about six times as long as the body, affording therefore a very extensive surface from which absorption may take place. That remnant of the chyme which the absorbents refuse, mixed with various depositions or secretions, continues its journey onwards and away.

Much of the process which we have now described is *mechanical,* as will appear immediately; other parts of it are *chemical,* such as the solution of the food by the gastric juice, the separation of the milky chyle, &c.: and parts are *vital,* such as the afflux, just when wanted, of saliva, gastric juice, bile, &c., and the muscular and absorbent actions. He who neglects the study of any one of these three classes of particulars, must have a very incomplete acquaintance with the function.—We proceed now to explain the mechanical or physical circumstances connected with digestion.

831. The abdomen may be considered as a vessel full of liquid, in which therefore there is pressure in all directions, increasing with the depth (see Hydrostatics), and increased also by the action of the surrounding muscles which form the sides of and compress the cavity.

The justness of this view of the abdomen becomes evident, when we consider that only moistened or semifluid food descends into the stomach, that drink follows, and that gastric and other juices are poured out to mix with the food as it passes on to occupy the long canal; and then that the separate organs have smooth surfaces, and are moistened by the constant secretion of

a lubricating serum, so that they slide among one another, without sensible impediment from friction. The abdomen, therefore, is, in fact, a roundish smooth vessel filled with a thick fluid, which is farther confined and moving along in a perfectly pliant and smooth-coated tube.

Thus any part of the contents of the stomach and bowels, in a living man, is supported like water in surrounding water, and therefore, if the whole contents be of nearly equal specific gravity, no part can descend or advance by its weight. Neither can any general pressure, or contraction of the surrounding parietes, hasten, except at the moment of expulsion, the motion of any contained matter—as has, however, often been supposed; nor can it help to empty one part into another—the stomach, for instance, or the gall bladder, into the small intestine.

For the same reason, however, the very slightest contractile action of any containing part is sufficient to dislodge its contents—gravity as a resistance being neutralized by the surrounding fluid. And when the gall-bladder, or stomach, or any part of the intestinal tube, becomes so full, as to put the elasticity of the coats ever so little upon the stretch, that circumstance alone, unless some muscular action oppose, will cause a motion onwards of the contents.—The natural action of the intestinal canal is a successive contraction of its circular fibres from above downwards, propelling the contents, just as if a small ring or tube were put round the canal and pushed forwards.

We hence see also the kind of error into which our predecessors fell so generally, when they attributed much of the digestive power of the stomach to its simple pressure upon the food. The idea probably arose from the contemplation of the stomach or gizzard of a fowl, which is a powerful gristly substance, answering the purpose almost of a mouth and teeth, as well as of a stomach.

When the abdominal muscles, which are the containing sides of the cavity, become tense, whether from unusual fulness of the cavity, or from their own action in any straining exertion, a variety of important mechanical effects ensue. Thus,

A full stomach produces — tension and projection of the abdomen—projection of the diaphragm upwards into the chest, causing hurried breathing, and impeding speech and singing—expulsion of blood from the abdominal vessels, and, therefore,

congestions elsewhere, as in the arteries of the head, sometimes producing apoplexy.

832. As a stomach-pump may not be always procurable when the occasion for it arises, all persons should be aware, that in many cases a simple tube will answer the purpose as well, if not better. Such a tube being introduced, and the body of the patient being so placed that the tube forms a downward channel from the stomach, all fluid matter will escape from the stomach by the tube, as water escapes from a funnel by its pipe; and if the outer end of the tube be kept immersed in liquid, there will be during the discharge a syphon-action of considerable force. On then changing the posture of the body, water may be poured in through the tube to wash the stomach, and may by the same channel be again discharged.

833. But there is a still easier mode than either of these now described, of dislodging poison from a torpid stomach, and which may be at once adopted where skilled help cannot be procured, *viz.*, merely to place the patient so that the mouth shall be considerably lower than the stomach,—as when the body lies across chairs or on a sofa, with the face near the floor,—and then if necessary, to press on the stomach with the hand. The cardiac orifice opens readily in such a case, and the stomach is emptied like any other inverted vessel.

The function of digestion or assimilation sketched in the preceding paragraphs, by which the animal body assumes foreign matters from around, and converts them into its own substance, is a subject of study little inviting in some of its details, but taken altogether is one of the most wonderful which can engage the human attention. It points directly to the curious and yet unanswered question—What is LIFE? The student of nature may analyze with all his art those minute portions of matter called *seeds* and *ova*, which he knows to be the rudiments of future creatures, and the links by which endless generations of living creatures hang to existence: but he cannot disentangle and display apart their mysterious LIFE! that something under the influence of which each little germ, when placed in suitable circumstances, gradually enlarges, to fill an invisible mould of maturity which determines its forms and proportions. One such substance thus expands into a beauteous rose-bush; another into a noble oak; a third into an eagle; a fourth into an elephant—yea, in the same way, out of the rude materials of broken seeds and roots, and leaves of plants, and portions of

animal flesh, is built up the human frame itself, with all its noble endowments. How passing strange, that such should be the origin of the bright eye, whose glance pierces as if the invisible soul were shot with it—of the lips which pour forth sweetest eloquence—of the larynx, whose vibrating fills the surrounding air with music; and, more wonderful than all, of that mass shut up within the bony fortress of the skull, whose delicate and curious texture seems to be the abode of the soul, with its reason which contemplates, and its sensibility which delights in these and the endless other miracles of creation.

THE GENERAL CONTENTS,

OR

ANALYTICAL TABLE.

PART I.

(*The Alphabetical Index is placed at the end of the work.*)

END OF PART I.

LONDON:
PRINTED BY W. CLOWES AND SONS, STAMFORD STREET
AND CHARING CROSS.